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PET'S CARBON PAWPRINT?

WHY WE DON'T HAVE TO GET OLD ANY MORE

THE AMBITIOUS PLAN TO TREAT OLD AGE LIKE A DISEASE – AND CURE IT

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Biobots
The Pac-Man-shaped living robots that can self-replicate

Michael Mosley
Why your sense of balance matters

Androids
The engineer behind the robot that broke the internet

This was Sylvia's promise to you...

A generation ago, a woman named Sylvia made a promise. As a doctor's secretary, she'd watched stroke destroy the lives of so many people. She was determined to make sure we could all live in a world where we're far less likely to lose our lives to stroke.

She kept her promise, and a gift to the Stroke Association was included in her Will. Sylvia's gift helped fund the work that made sure many more of us survive stroke now than did in her lifetime.

Sylvia changed the story for us all. Now it's our turn to change the story for those who'll come after us.

Stroke still shatters lives and tears families apart. And for so many survivors the road to recovery is still long and desperately lonely. If you or someone you love has been affected by stroke – you'll know just what that means.

But it doesn't have to be like this. You can change the story, just like Sylvia did, with a gift in your Will. All it takes is a promise.

You can promise future generations a world where researchers discover new treatments and surgeries and every single stroke survivor has the best care, rehabilitation and support network possible, to help them rebuild their lives.

Big or small, every legacy gift left to the Stroke Association will make a difference to stroke survivors and their families.

Find out how by calling 020 7566 1505
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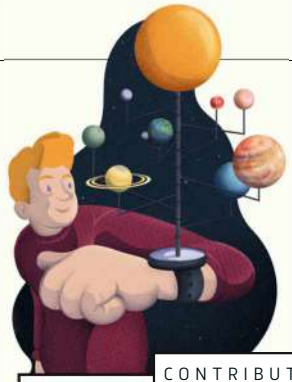
Rebuilding lives after stroke

The Stroke Association is registered as a charity in England and Wales (No 211015) and in Scotland (SC037789).
Also registered in the Isle of Man (No. 945) and Jersey (NPO 369), and operating as a charity in Northern Ireland.

Stroke Association



Have we discovered anything in space that we now use in real life? →p79

FROM THE EDITOR

What if you didn't have to get old? What if there was a way to immunise yourself against the inevitable consequences of ageing? No more creaky knees, sore back, or failing eyesight. No more trips to the doctor that end in: "Well, that's just how your body works now." Instead, what if you could live in a body that worked as well in your 40s, 50s and 60s, as it did in your 20s?

It sounds too good to be true (and being forever 21 might just be out of reach), but the idea that we can treat old age like a disease is a school of thought that's drawing attention from scientists and policymakers around the world. The theory goes that if we can target the mechanisms that age us at a cellular level and counteract those processes with drugs, we might be able to slow ageing. As luck would have it, it seems that some people might already have been taking a drug that's helped them stay healthier for longer and even live a few years longer without even knowing it. Head to p52 to discover why one day we might not need to get old any more.

Finally, if you're looking to pick up some new good habits in the New Year, why not check out our podcast *Instant Genius*? We've got Dr Matthew Walker talking to us about improving your sleep, Dr Michael Mosley on simple health hacks and Kimberley Wilson on how to feed your brain.

Enjoy the issue!

Daniel Bennett, Editor

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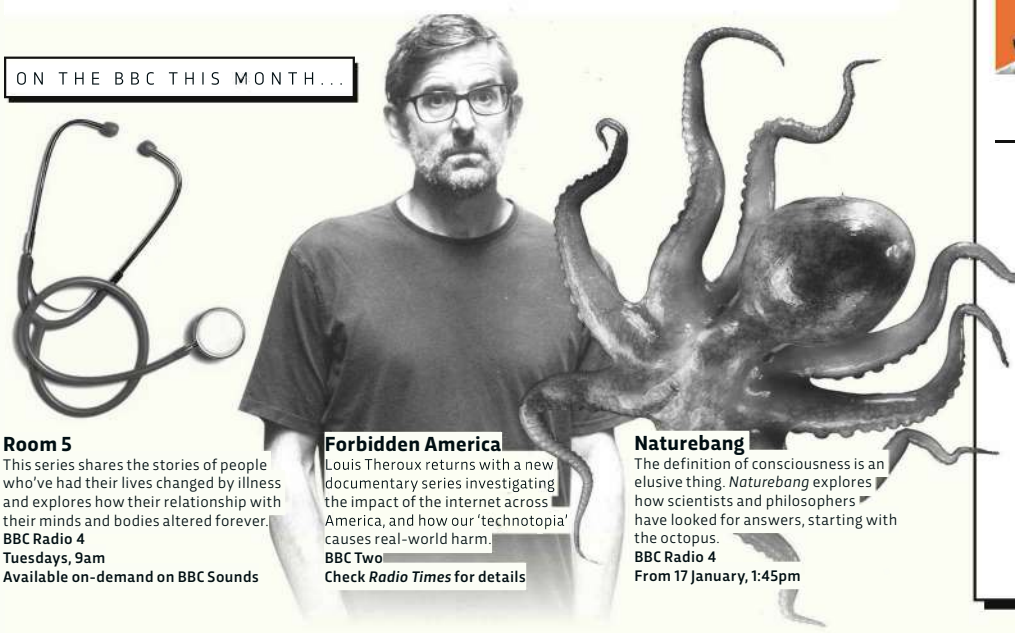

Room 5
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Forbidden America
Louis Theroux returns with a new documentary series investigating the impact of the internet across America, and how our 'technotopia' causes real-world harm.
BBC Two
Check *Radio Times* for details

Naturebang
The definition of consciousness is an elusive thing. *Naturebang* explores how scientists and philosophers have looked for answers, starting with the octopus.
BBC Radio 4
From 17 January, 1:45pm

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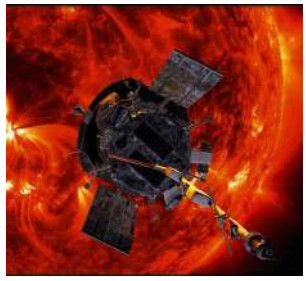

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"THE ANTS DEPOSITED THE MATERIAL IN THE NEST, THEN FUNGI STARTED GROWING ON IT AND THEY REALISED, "HEY, THIS IS NICE"

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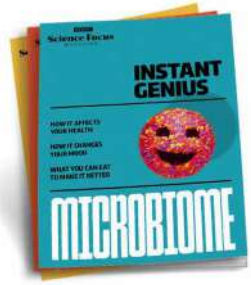

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EYE OPENER

An ash blanket

LA PALMA,
CANARY ISLANDS

This scene shows the vast amount of ash that covered the island of La Palma after its volcano, Cumbre Vieja, started erupting on 19 September.

"The first week was chaotic, no one really knew what was going on," says Ben Ireland, a junior volcanologist with GeoTenerife, who was 120km from the island when the eruption started. "A few months later, even though the volcano was still going, it was a lot calmer."

This is the ninth eruption on La Palma since records began in the 1400s and is the longest running eruption the island has known.

"Ash is just tiny fragments of magma," explains Ireland. "Magma coming up the conduit has got lots of gas in it, and as it rises up and the pressure decreases, this gas expands. That's why you see those explosions when volcanoes are erupting – it's gas fragmenting the magma into lots of tiny pieces."

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EYE OPENER

So long, smog

GURUGRAM, INDIA

In November 2021, pollution levels in India reached unprecedented levels. Schools in New Delhi were closed and anti-pollution measures were rolled out, including anti-smog guns like the one shown here.

The guns mimic a natural anti-smog event: rain. "Consider a hazy day in a city. After a period of rain, the sky is clear and when we breathe the air feels fresher," explains Dr Kenneth Park, a professor working on similar technology at Northwestern University.

The anti-smog guns spray out water droplets that encapsulate the smog particles and pull them down to the ground. On their own, the smog particles are so small and light that they are kept aloft by forces in the air.

While these devices work well in India, Park explains that there are many regions with critical smog and pollution problems that cannot afford to use water in this way. "In many areas, water is more precious than the air."

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EYE OPENER

Rippling rubble

MARS

Mars is dimpled with craters, some as large as 100km in diameter, but this particular site is just 6km wide – about the same as 60 football pitches. The crater was found in the northern hemisphere of Mars and photographed by CaSSIS, a camera system attached to an orbiter currently monitoring Mars's atmosphere.

"This guy was found near Albert Patera, one of Mars's volcanic areas," says Prof Nicolas Thomas, principal investigator for CaSSIS. It was imaged when the Sun was low in the sky, causing the lower crater wall to cast a shadow over itself.

Grooves inside the crater resemble ripples caused by throwing a stone into a pond.

"The impactor itself was almost certainly vaporised during the collision," explains Thomas. "But these grooves arise from a blast wave scattering larger dust particles while the crater was being formed."

NASA/ESA

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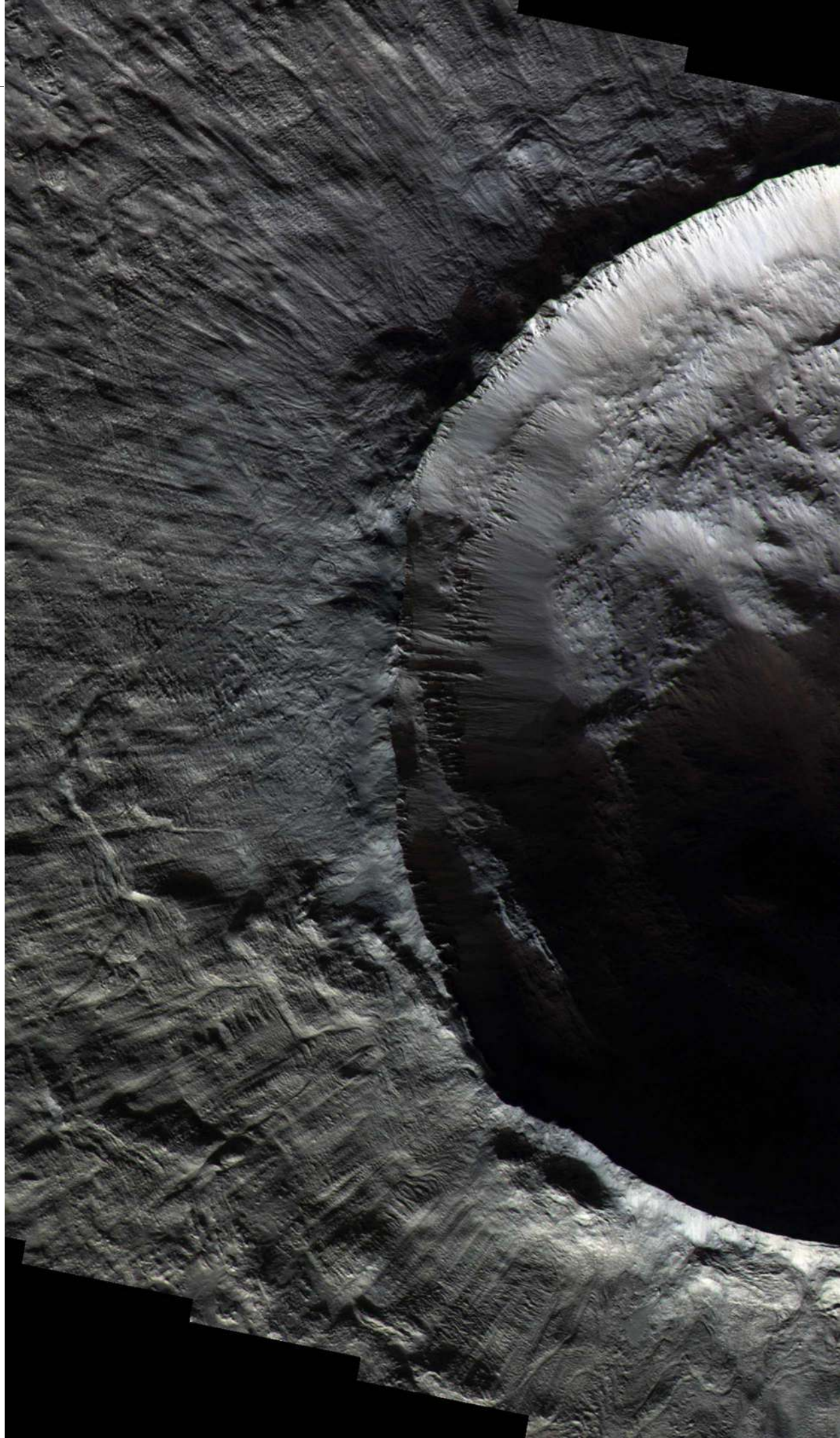

CONVERSATION

YOUR OPINIONS ON SCIENCE, TECHNOLOGY AND *BBC SCIENCE FOCUS*

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LETTER OF THE MONTH

It's been quite a year

I love the end of each year as it is the time for a good old retrospective look at what has occurred in the previous 12 months, and so I was highly pleased to see my trusty *BBC Science Focus* news review 2021 (December, p22). Given how COVID-19 and the science around it have dominated our thinking, many of the science discoveries passed me by in the chaos. The story on the continued revelations surrounding CRISPR gene-editing techniques and the amazing feats that can be achieved was most welcome and eye-opening. The advancement of being able to inject a patient without the need to extract and work on changing the cells outside the body first is a game-changer. I am pleased for the patient who saw a drastic reduction in the destructive proteins caused by their transthyretin amyloidosis.

Luke Russell, Wakefield

WRITE IN AND WIN!

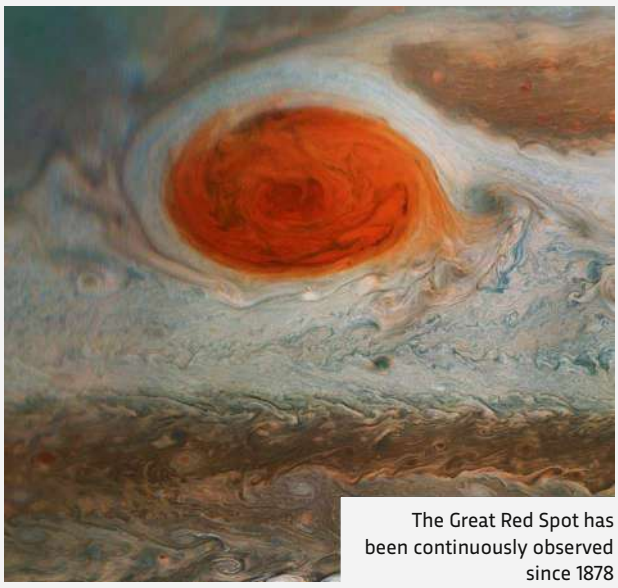
The writer of next issue's *Letter Of The Month* wins **a year's subscription to *BBC Science Focus*.** That's 14 issues of the latest news and features from the worlds of science and technology, delivered directly to your door! **sciencefocus.com**

Great red... whirlpool?

Is Jupiter's Great Red Spot really a storm (December, p20)? Could it instead be caused by an object protruding above the surface or a hole beneath it, creating a whirlpool effect more like a liquid? Personally, I think a storm is a misnomer because what storm stays in the same place for years? Conversely, what whirlpool or maelstrom moves (Corryvreckan, Saltstraumen, Moskstraumen, for instance)?

Tony Sandy

The atmospheric conditions on Jupiter are very different from those on Earth. There are strong atmospheric currents (which we see as the planet's stripes) that keep the storms within them firmly locked in place. There is also a lot more energy available, which helps to feed these giant storms and keep them going for years at a time. We don't know exactly why the Great Red Spot is so large or why it has gone on for so long, so there could be something happening further down that's causing it. What we do know is that it is a



The Great Red Spot has been continuously observed since 1878

"THE BIG TECH COMPANIES ARE PROPELLING THE METAVERSE FORWARD WITH VIGOROUS PRESS RELEASES AND STARRY-EYED HOT TAKES BORDERING ON THE MESSIANIC"

DR ALEKS KROTOSKI, P62

The premiere of Beethoven's 10th Symphony, as completed by an AI

GETTY IMAGES X2, NASA

disturbance in Jupiter's atmosphere, which we refer to as a 'storm', whereas maelstroms or whirlpools take place in liquids. Though the mechanics might be more like the latter (which we don't know if they are or aren't), the medium is what matters when it comes to the terminology. As we learn more, scientists might come up with a new term.
Dr Elizabeth Pearson, news editor, *BBC Sky At Night Magazine*

Beethoven bot? Pah!

The article by the learned professor is interesting, but he is directly insulting to anybody who does not agree with his view that AI will be able to complete a Beethoven symphony (November, p24). He asserts that they are afraid of AI taking their jobs. How dare he? I have no job to lose, but I have an honours degree in computer science and I disagree with him. For me, music, like all artistic endeavours, is a means of communication between minds. How can an AI achieve this unless it is a mind itself? The results will have to speak for themselves.
James McCosh, Somerset

Just gimme the treats

Your September issue (p16) had a short news story of a dog treat being hidden in one of two bowls, and a researcher pointing to one of the bowls. Half of the dogs ignored the humans when they pointed to the wrong bowl. You're reading too much into this. Obviously the dogs could smell which bowl had the treat. They couldn't care less what the human was doing when they already knew what was at stake.
Steven Halasz, Buffalo

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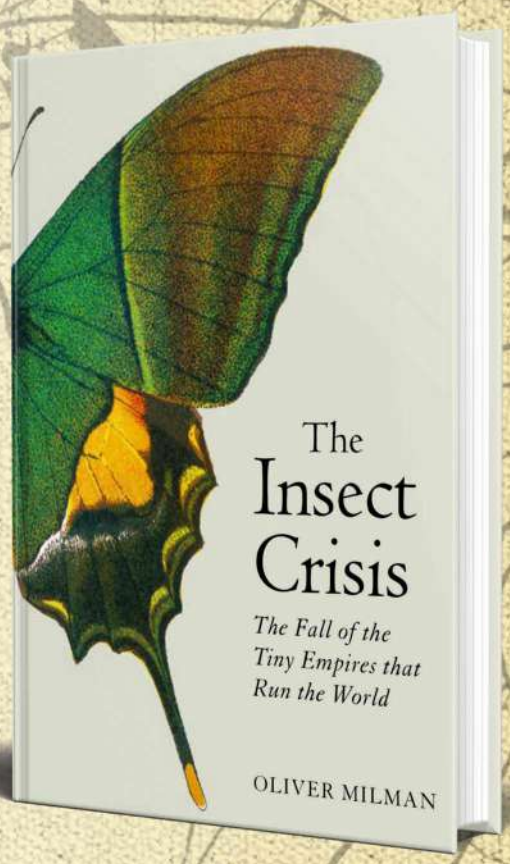

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DISCOVERIES

NASA's Parker Solar Probe is the first human-made object to encounter the Sun's corona

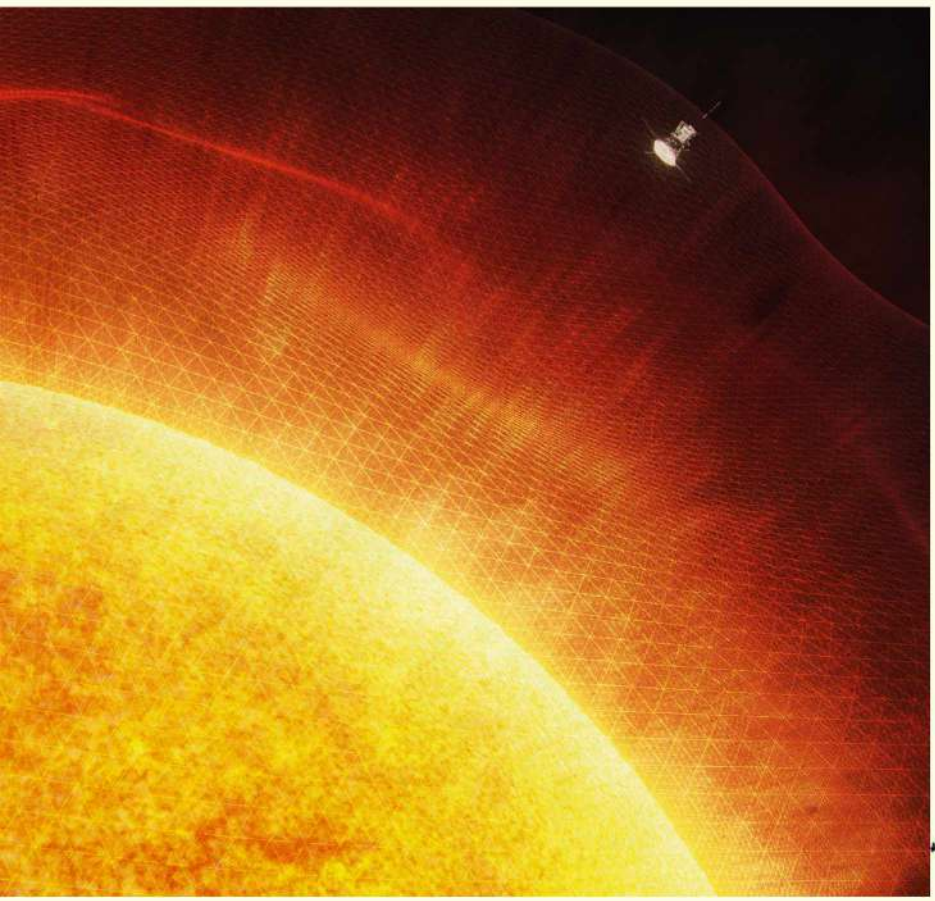
BEN SMIT/APPLIED PHYSICS LABORATOR/NASA

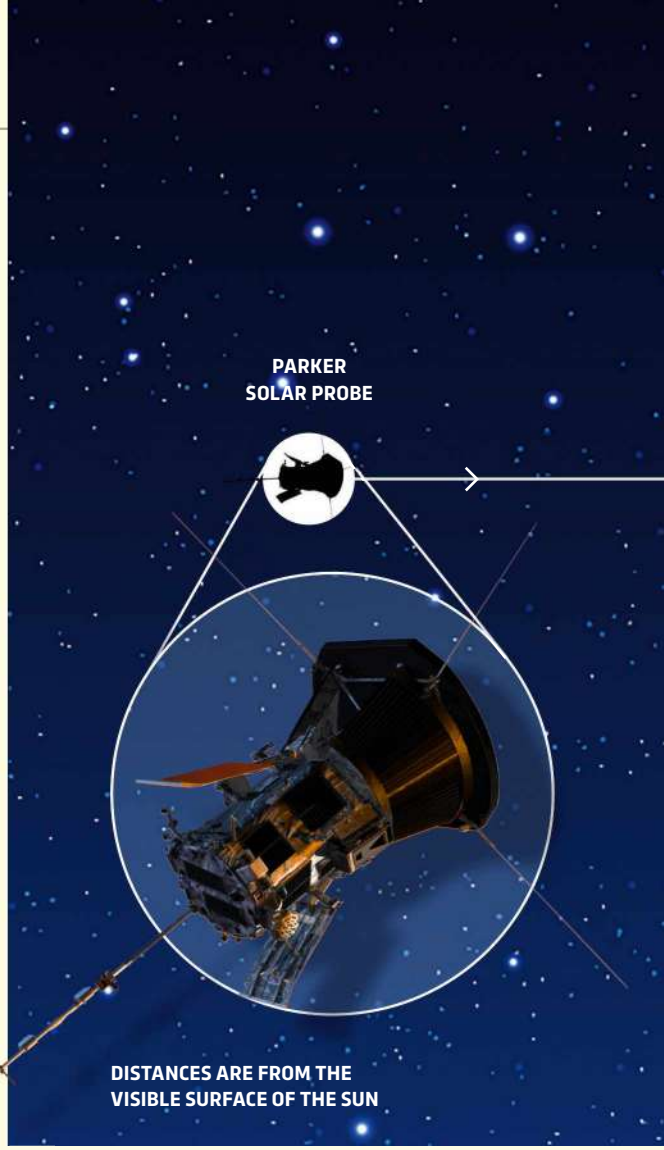
ASTRONOMY

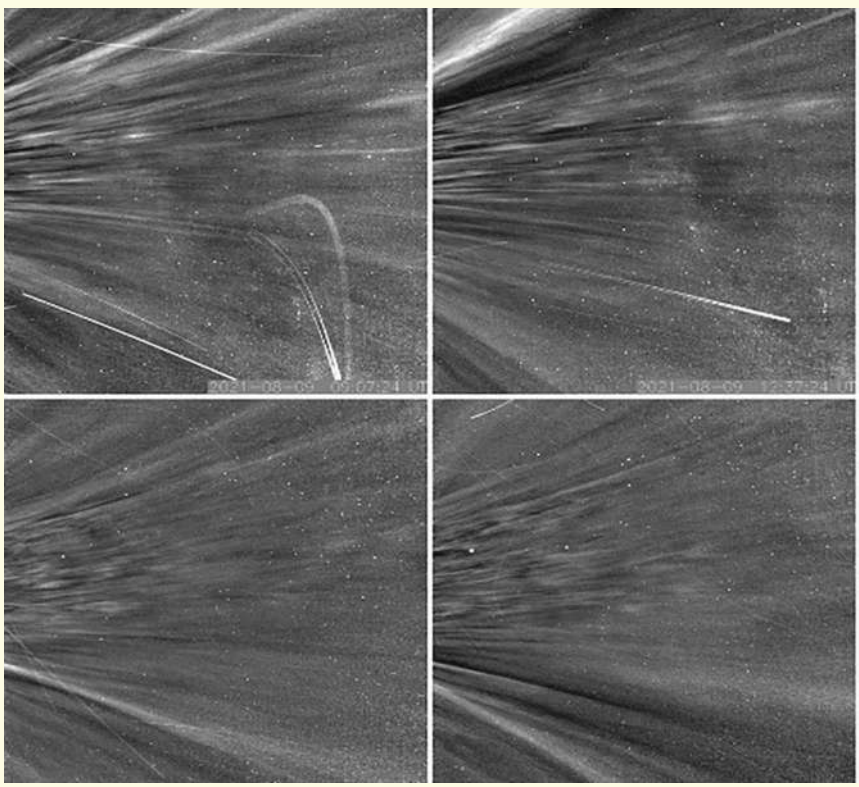
NASA'S SOLAR PROBE 'TOUCHES' THE SUN

The Parker Solar Probe is part of the way through its seven-year mission to investigate the inner workings of our nearest star

Fit as a butcher's dog Selective breeding may improve health of French bulldogs p22 **Dinosaur treasure trove** Palaeontologists find immaculately preserved fossils in Italy p24 **Bio-bots** Living 'robots' that can reproduce – as long as they look like Pac-Man p26







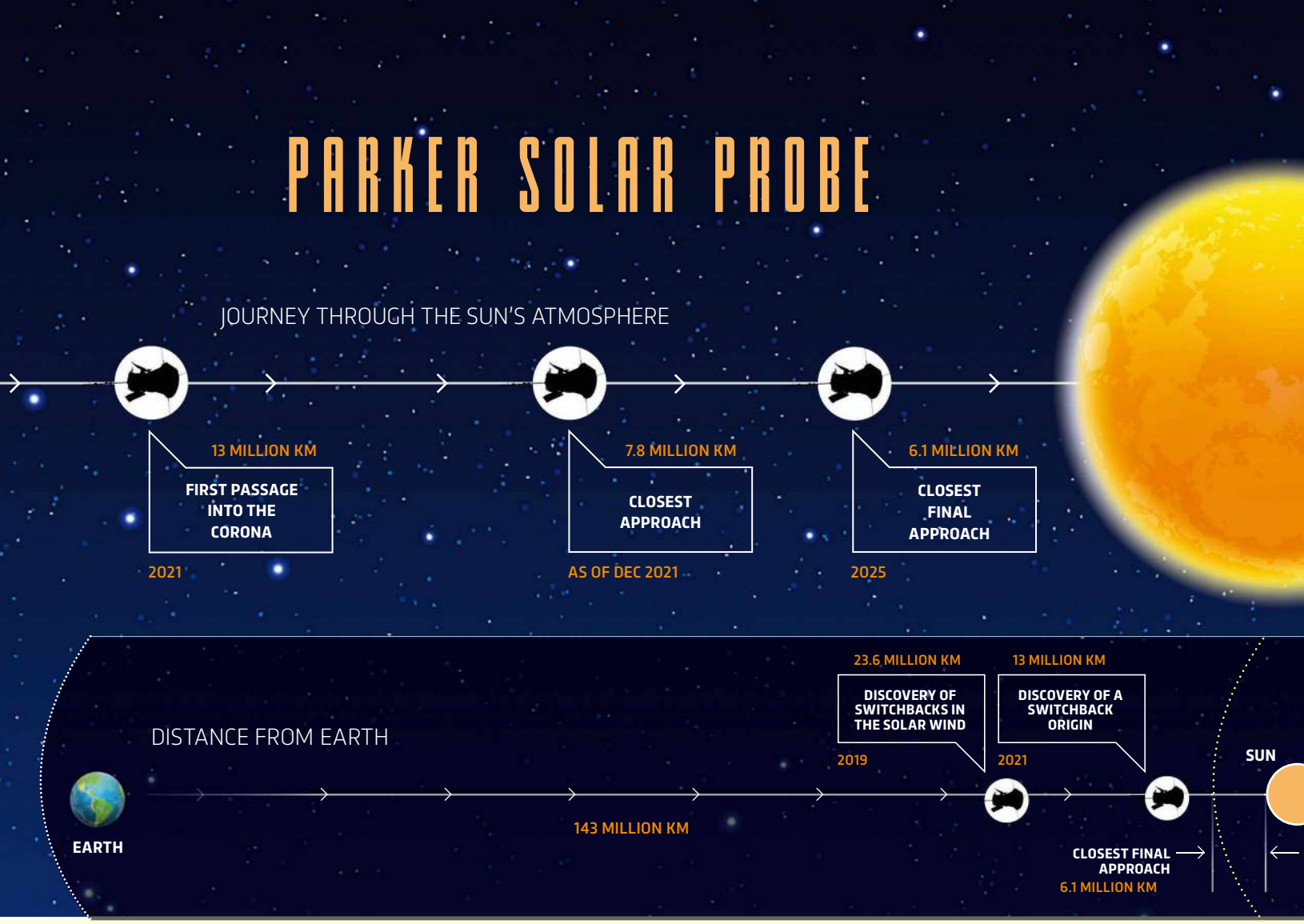
BEN SMIT/APPLIED PHYSICS LABORATORY/NASA, NASA/JOHNS HOPKINS APL/ILLO BY TIDYDESIGNS

NASA's Parker Solar Probe has made history after becoming the first spacecraft to plunge into the Sun's atmosphere. The milestone journey was made on 28 April 2021, nearly three years after the probe's launch in August 2018. It happened during Parker's eighth flyby of the star at the centre of our Solar System. The probe spent a total of five hours travelling amid the plasma and solar winds in the Sun's upper atmosphere, or corona.

The landmark event was not announced until 14 December because the data recorded by the probe took several months to reach Earth, and then several more to be processed and analysed by scientists.

"We were fully expecting that, sooner or later, we would encounter the corona for at least a short duration of time," commented Dr Justin Kasper, lead author of the paper that announced the historic flyby, published in *Physical Review Letters*. "But it is very exciting that we've already reached it," said Kasper, who is associate professor of climate and space sciences and engineering at the University of Michigan.

"This marks the achievement of the primary objective of the Parker mission and a new era for understanding the physics of the corona."



ABOVE LEFT An artist's impression of the Parker Solar Probe's first passage into the Sun's corona

LEFT Parker caught images of streamers (the bright features moving upwards through images in the top row and downwards in the bottom). These magnetic 'ribbons' in the Sun's corona are only usually visible during solar eclipses

Parker spent five hours exploring the Sun's atmosphere beneath a boundary known as the Alfvén critical surface – the point at which the star's powerful gravitational and magnetic fields are no longer strong enough to prevent solar winds from escaping out into the Solar System, to Earth and beyond. During this time, the craft passed above and below the boundary a total of three times.

"We have been observing the Sun and its corona for decades, and we know there is interesting physics going on there to heat and accelerate the solar wind plasma. Still, we cannot tell precisely what that physics is," said Dr Nour E Raouafi, the Parker Solar Probe project scientist at Johns Hopkins University's Applied Physics Lab. "With the Parker Solar Probe now flying into the magnetically dominated corona, we'll get the long-awaited insights into the inner workings of this mysterious region."

Until now, researchers were unsure exactly where the Alfvén critical surface lay. Early results from Parker show that it lies about 13 million kilometres above the nearest thing the Sun has to a surface. The data show the Alfvén critical surface is wrinkled and suggest that these wrinkles may be caused by a pseudostreamer – a giant magnetic formation that rises above the Sun's 'surface' and can be seen from Earth during solar eclipses.

This first passage through the corona is just one of many planned for Parker. It's hoped that the probe will continue to spiral closer to the Sun, eventually coming to within six million kilometres of its 'surface'.

Upcoming flybys, the next of which is planned for January 2022, will likely bring Parker into the corona again.

"I'm excited to see what Parker finds as it passes through the corona in the years to come," said Dr Nicola Fox, director of NASA's Heliophysics Division. "The opportunity for new discoveries is boundless."

The size of the corona is also driven by solar activity. As the Sun's 11-year activity cycle reaches its peak, the corona will expand, giving the Parker Solar Probe a greater chance of being inside the Sun's atmosphere for longer periods of time.

"It's a really important region to get into because we think all sorts of physics potentially turn on," Kasper said. "Now we're getting into that region and will hopefully start seeing some of these physics and behaviours."

HEALTH

Elderly with elevated heart rates may be at greater risk of dementia

The discovery could help doctors to identify people with higher dementia risk for early intervention

There are currently 850,000 people in the UK living with dementia, according to figures compiled by Alzheimer's Research UK. This figure is expected to rise to one million by 2025, and two million by 2050.

It is currently the only disease in the UK's top 10 causes of death without an effective treatment to prevent, cure or slow its progression, but there is growing evidence that maintaining cardiovascular health could help delay the onset of the disease and ease symptoms.

Now, researchers at the Karolinska Institute in Sweden have found evidence that links elevated resting heart rates in old age to a higher risk of dementia.

Since resting heart rate is simple to measure and can be lowered through regular exercise or the use of medication, the researchers say it may be a method of identifying and treating those with a higher risk of developing dementia before the disease progresses too far.

The team monitored the resting heart rates of 2,147 participants living in Stockholm, Sweden, aged 60 and over for up to 12 years. They found that those with resting heart rates of 80 beats per minute or higher on average had a 55 per cent higher risk of developing dementia than those with a heart rate of 60 to 69 beats per minute.

> **"Resting heart rate could identify patients with high dementia risk"**

The connection remained even when the team adjusted for other potential known risk factors, such as cardiovascular disease. However, the researchers note that undetected cardiovascular events may have affected the results, or that more participants with cardiovascular disease died during the study period and so didn't have time to develop dementia.

"We believe it would be valuable to explore if resting heart rate could identify patients with high dementia risk," said the study's lead author Yume Imahori at the Karolinska Institute. "If we follow such patients' cognitive function carefully and intervene early, the onset of dementia might be delayed, which can have a substantial impact on their quality of life."

BIOLOGY

Gene editing used to create all-male or all-female litters of mice

The breakthrough could help to stop the culling of livestock and animals used in scientific research

As males are unable to produce milk or lay eggs, the ability to breed cows and hens that produce all-female offspring is likely to be high on most dairy and poultry farmers' wishlists.

Now, scientists at the Francis Crick Institute and the University of Kent have come a step closer to realising this goal after successfully using CRISPR gene-editing techniques to produce all-female or all-male litters of mice.

Females normally have two X chromosomes (XX). A female inherits one X chromosome from her mother and one X chromosome from her father. Males normally have an X and a Y chromosome (XY). A male inherits an X chromosome from his mother and a Y chromosome from his father.

To make the breakthrough, the researchers took advantage of the fact that CRISPR consists of two parts – the Cas9 enzyme, which cuts the DNA and enables scientists to alter specific regions of genes, and the guide RNA, which carries the Cas9 enzyme to the desired region on the genome.

The researchers targeted the TOP1 gene. In mice, disruption of TOP1 causes embryos to fail at an early stage. To make a female-only litter, they placed the Cas9 enzyme onto the father's Y chromosome, meaning that it will only be inherited by male embryos, and the other part on the mother's X chromosome, which will be inherited by all embryos. This meant that when a sperm carrying the Cas9 enzyme on the father's Y chromosome fertilised an egg carrying the guide RNA, the gene-editing process was triggered in the resulting male embryo and it was not able to develop beyond a very early stage. To make male-only litters, the Cas9 enzyme was placed on the father's X chromosome.

"This method works as we split the genome-editing process in half, between a male and female, and it is only when the two halves meet in an embryo through breeding that it is activated. Embryos with both halves cannot develop beyond very early cell stages," said Charlotte Douglas, first author and former PhD student and postdoctoral scientist at the Crick.

Using this method, the researchers were able to control the sex of a litter with 100 per cent accuracy and found no harmful effects in the surviving animals. Moreover, as the TOP1 gene is well conserved across mammals, these results may also be applicable to other animals such as livestock.

"The implications of this work are potentially far-reaching when it comes to improving animal welfare, but should be considered at ethical and regulatory levels," said Dr Peter Ellis, author and senior lecturer in molecular genetics and reproduction at the University of Kent.

"In particular, before any potential use in agriculture, there would need to be extensive public conversation and debate, as well as changes to legislation. On the scientific side, there is also much work to be done over a number of years. Further research is needed, first to develop the particular gene editing toolkits for different species, and then to check they are safe and effective."

Scientists have been able to produce single-sex litters of mice with 100 per cent accuracy

GETTY IMAGES, FRANCIS CRICK INSTITUTE

Quetzalcoatlus made vertical take offs instead of relying on runways

PALAEONTOLOGY

Palaeontologists gure out how a pterosaur the size of a double-decker bus was able to fly

Quetzalcoatlus, the largest known animal capable of ight, launched itself into the air using its powerful legs

With a 10-metre wingspan, which is as long as a London Routemaster bus, the giant pterosaur *Quetzalcoatlus* is the largest known animal to ever take to the sky. But as there are only a few fossilised bones to go on, experts have only been able to speculate about how this prehistoric behemoth was capable of getting airborne.

Now, a team of researchers at the University of Texas at Austin think they have the answer: *Quetzalcoatlus* likely leapt three metres into the air before flapping its gigantic wings and flying away.

It's thought a 'running start' wouldn't have worked for the *Quetzalcoatlus* as being on the ground would prevent it from flapping its wings deep enough to generate sufficient lift.

The 'Texas Pterosaur', as it is sometimes known, was discovered in Big Bend National Park in 1971. But apart from some initial descriptions of the bones, almost no scientific studies have been carried out on the enigmatic animal.

"This is the first time that we have had any kind of comprehensive study," said Matthew Brown, director of the University of Texas at Austin's vertebrate palaeontology collections. "Even though *Quetzalcoatlus* has been known for 50 years, it has been poorly known."

The team made the discovery by studying all confirmed and suspected *Quetzalcoatlus* bones, along with other pterosaur fossils recovered from Big Bend. This enabled them to identify a smaller species of *Quetzalcoatlus* with a five-metre wingspan. They pieced together an almost complete skeleton of this smaller species and scaled it up to the size of *Quetzalcoatlus*.

The two species both called Big Bend home about 70 million years ago. Whereas the smaller species most likely lived in flocks, the larger species may have lived alone, hunting in rivers and streams, much like the modern-day heron.

Darren Naish, a palaeozoologist and pterosaur expert who was not involved with the research, said: "To say that this work is long awaited is an understatement. The good news is that it very much delivers. Never before has so much detailed information on azhdarchids [the pterosaur family that includes *Quetzalcoatlus*] been gathered in the same place. This work will serve as the standard go-to study of this group for years – probably decades – to come."

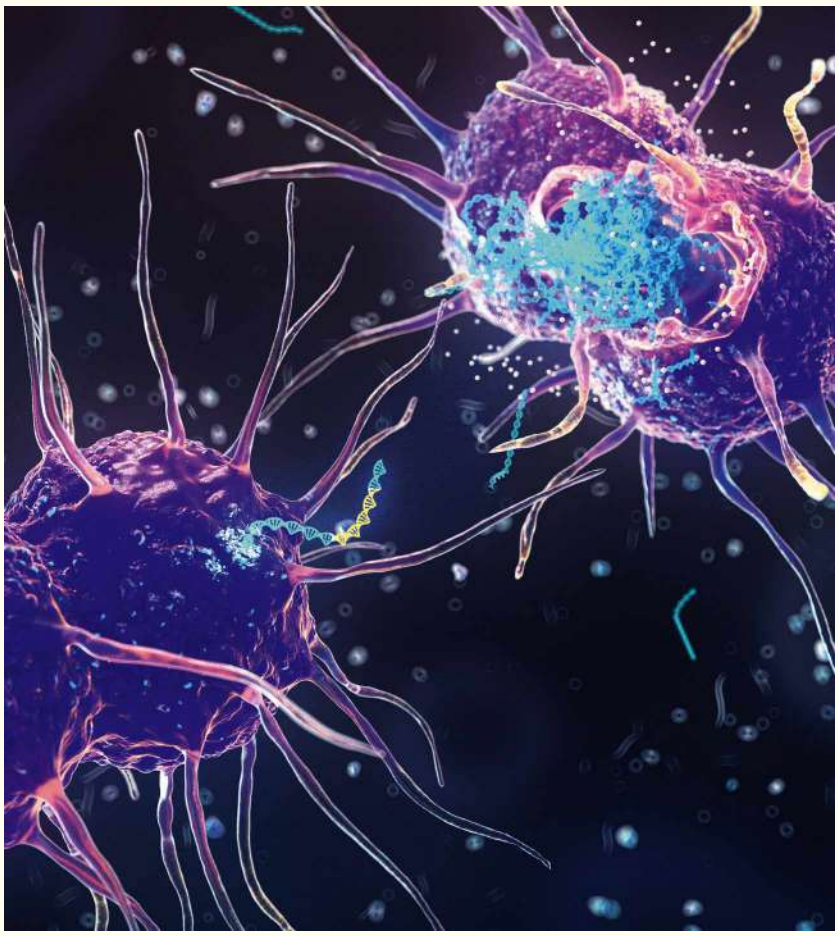
JAMES KUETHER, GETTY IMAGES

HEALTH

Method of predicting which bacteria are likely to become resistant to antibiotics developed

The researchers made the discovery by studying the emergence of 'pre-resistance' in tuberculosis bacteria

Antibiotic resistance is one of the biggest threats to our health today. But by studying tuberculosis, a team of scientists at University College London and Great Ormond Street Hospital have found a way to establish which bacteria are likely to become resistant to antibiotics in the future. It's a breakthrough that could help doctors to select the best treatments for infections.



BELOW An illustration showing how genetic material conferring antibiotic resistance is released and passed between bacteria

Tuberculosis is a bacterial lung infection that is estimated to have killed more than one billion people over the past 200 years and is still one of the world's most deadly diseases. In 2020 it was the second leading infectious cause of death after COVID-19, killing 1.5 million people.

While tuberculosis can be cured with the right antibiotics, treatment can take a long time and many people do not have access to good healthcare. Drug-resistant tuberculosis can develop when people do not complete their course of treatment, or when effective drugs are not available.

Tuberculosis that is resistant to multiple drugs is a huge burden on healthcare, and totally drug-resistant strains have been detected in a handful of countries.

In order to improve understanding of tuberculosis, and ultimately develop better treatments, this new research has identified how to pre,empt drug,resistant mutations before they occur. The researchers have termed this concept 'pre-resistance': when a disease-causing pathogen has a greater inherent risk of developing resistance to drugs in the future.

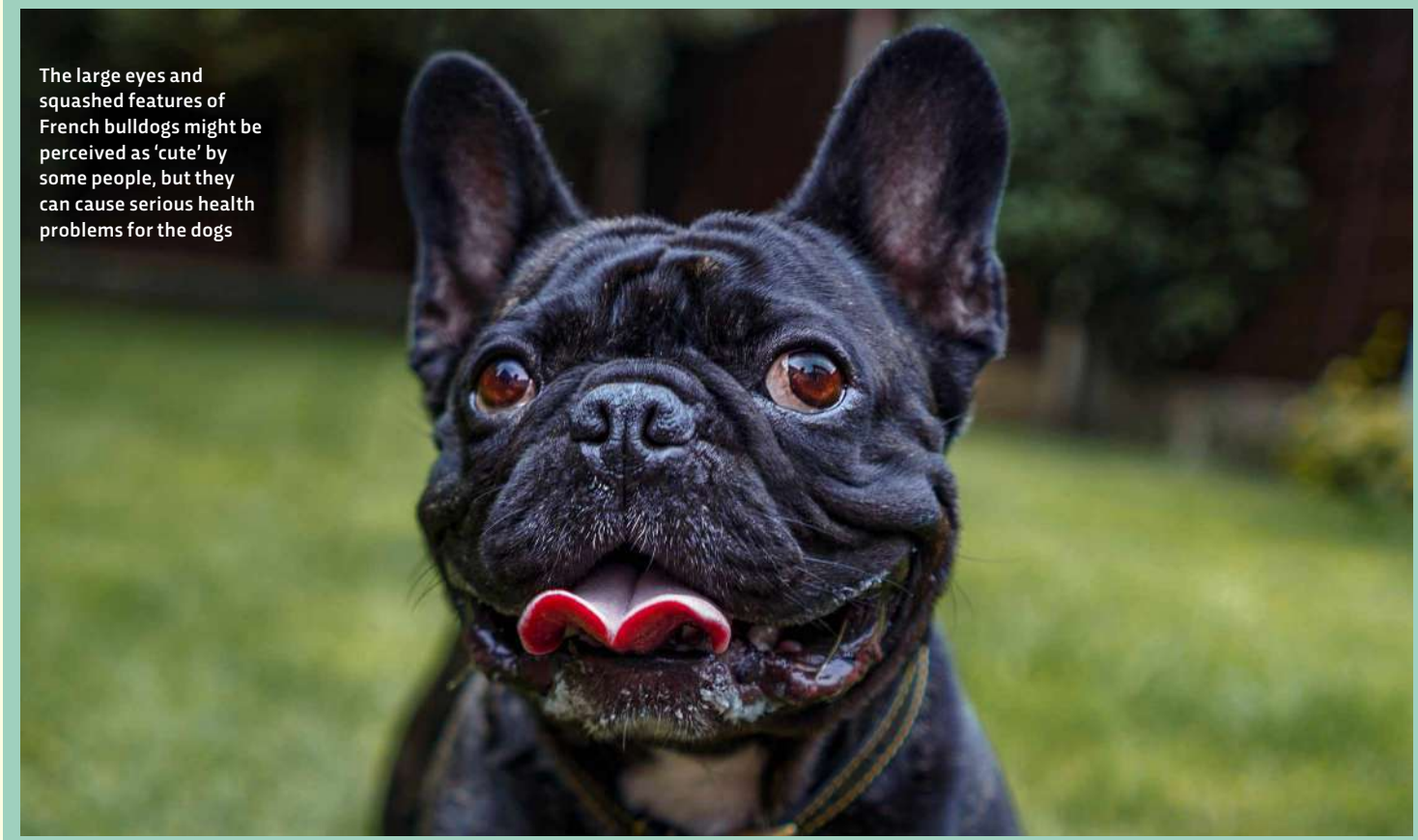
To find out which strains of tuberculosis bacteria showed pre-resistance to antibiotics, the researchers, in collaboration with the Peruvian Tuberculosis Programme, sequenced the genomes of 3,135 tuberculosis samples taken from the suburbs of Lima, Peru, over a 17-year period.

They then compared these samples to create a tuberculosis family tree to identify key changes in the genetic codes of the bacteria that went on to develop drug resistance. They described how variations in the tuberculosis genome predicted that a particular branch of the family tree would likely become drug resistant, and then validated their findings in an independent global tuberculosis data set.

"We're running out of options in antibiotics and the options we have are often toxic – we have to get smarter at using what we have to prevent drug resistance," said Dr Louis Grandjean, senior author of the study. "This is the first example of showing that we can get ahead of drug resistance. That will allow us, in the future, to use the pathogen genome to select the best treatments."

PETS

Frenchies more at risk of common health disorders than other breeds



The large eyes and squashed features of French bulldogs might be perceived as 'cute' by some people, but they can cause serious health problems for the dogs

Selectively breeding away from these health issues could mean that French bulldogs start to look di erent in the future

French bulldogs are more likely to be diagnosed with 20 common health disorders when compared to other dog breeds, a new study published in the journal *Canine Medicine And Genetics* has found. Among the health concerns, researchers found that French bulldogs had a greater proclivity towards narrowed nostrils, obstructive airway syndrome, ear discharge and skin dermatitis.

But it's not all bad news. They also found that French bulldogs are less likely to be diagnosed with 11 out of the 43 specific disorders when compared to other breeds. For example, they are much less likely to experience undesirable behaviour, lameness and obesity. This suggests the breed has the potential to have a healthier profile over time, with researchers proposing a move towards breeding for more moderate traits.

Selectively breeding to reduce the high-risk physical features of the breed could improve the overall health of the French bulldog, researchers say. This could include moving away from shorter muzzles and skin folds, as well as lessening the risks of the breathing issues associated with the typical shorter muzzle and flat head of the breed.

Using reports from veterinary practices across the UK, the team from the Royal Veterinary College in Hertfordshire examined records from 2,781 French bulldogs and 21,850 other dogs.

"Achieving meaningful changes to the typical look of French bulldogs over time requires buy-in from breeders and kennel clubs who publish breeding standards," said Dr Dan O'Neill, a co-author of the study and senior lecturer at the Royal Veterinary College. "But the biggest responsibility lies with owners who ultimately can demand dogs with more moderate features."

And there's potentially more good news for the future of the breed.

"The Kennel Club has recently updated the breed standard for the French bulldog to move further away from elements of extreme conformation with evidence of health ill effects," said O'Neill. "This is a very positive step to prioritise the health of dogs over human desires for how these dogs look and we must now continue this evolution of the breed towards a more moderate conformation."

HEALTH

A genetic form of hearing loss could be reversed

A recent study performed on mice could lead to new therapies for patients with hearing loss

Despite the fact that genetic hearing loss can be linked to at least 100 different genes, just one single gene, STRC, is associated with up to 16 per cent of cases. Now, a new kind of gene therapy could help to reverse severe hearing loss linked to this gene.

The STRC gene encodes for the protein stereocilin, which plays a small but integral part in our hearing. For us to be able to hear sounds, hair cells in the inner ear need to make contact with the ear's tectorial membrane (a tissue that plays a role in transforming sound to stimulation). Stereocilin acts like a support, helping the hair cells stand up in a neat, organised bundle so the tips can touch the membrane.

In the study, researchers at Boston Children's Hospital successfully replaced mutated stereocilin in the inner ear of mice. This reversed severe hearing loss and in some cases, returned completely normal levels of hearing. To deliver the healthy gene into the hair cells of the mice, the team used a synthetic adeno-associated virus (AAV) vector. AAV only causes mild immune responses and is a predictable virus, so it is quickly becoming a popular tool in gene therapy.

"If stereocilin is mutated, you don't have that contact [with the tectorial membrane], so the hair cells are not stimulated properly," said Dr Jeffrey Holt, a scientist at the Boston Children's Hospital and the study's senior investigator. "Importantly, the hair cells still remain functional, so they are receptive to the gene therapy. We think this will provide a broad window of opportunity for treatment – from babies to adults with hearing loss."

The team did, however, run into a problem with this approach.

"The challenge we faced was that the gene for stereocilin is too big to fit into the gene-therapy vector," Holt said.

To get around this, the study's first author Dr Olga Shubina-Oleinik came up with the solution of splitting the gene in two and putting the two halves into separate viruses in a recombination of the proteins.

To check the hearing of the mice after treatment, the researchers used two different tests. The first was similar to hearing tests carried out on babies, and the second monitored brainstem responses to different sound frequencies using electrodes on the scalp.

The researchers found that the mice were more sensitive to subtle sounds and had an increased ability to amplify soft sounds, tamp down the response to loud sounds and discriminate between different frequencies.

"It turns out that STRC gene variations are more common than we thought, which makes gene therapy for this disorder so important," said Dr Eliot Shearer, a co-author of the study.

Holt and his team have now filed a patent application for this gene-therapy technology.

"We think this will provide a broad window of opportunity for treatment – from babies to adults with hearing loss"

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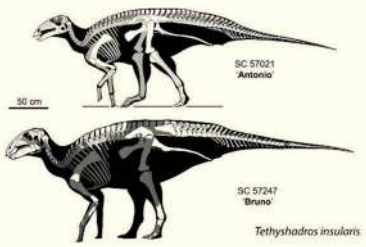

PALAEONTOLOGY

Dinosaur treasure trove unearthed in Italy

Palaeontologists from the University of Bologna have unearthed a cache of 11 immaculately preserved dinosaur fossils in Villaggio del Pescatore, near Trieste, in northeastern Italy.

The skeletons are the biggest and most complete ever to be found in Italy and belong to the species *Tethyshadros insularis*, which stalked the Mediterranean approximately 80 million years ago.

1

2

DAVIDE BONADONNA, UNIVERSITY OF BOLOGNA, ZOIC SRL, A GIAMBORINO/SOPRINTENDENZA ARCHEOLOGIA
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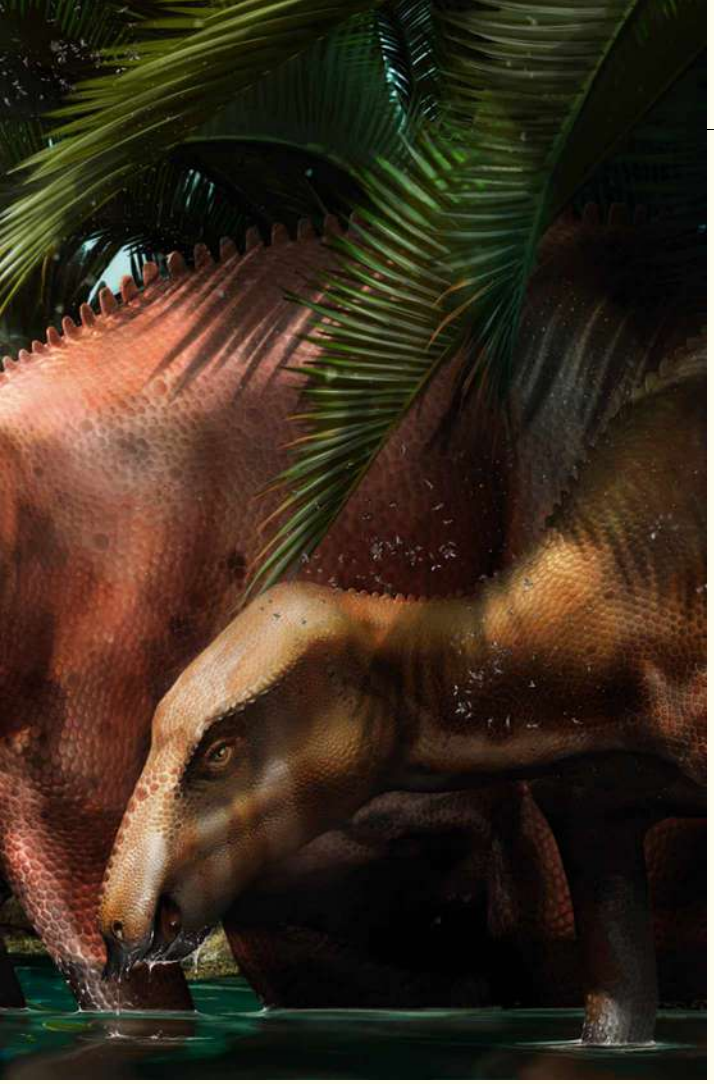

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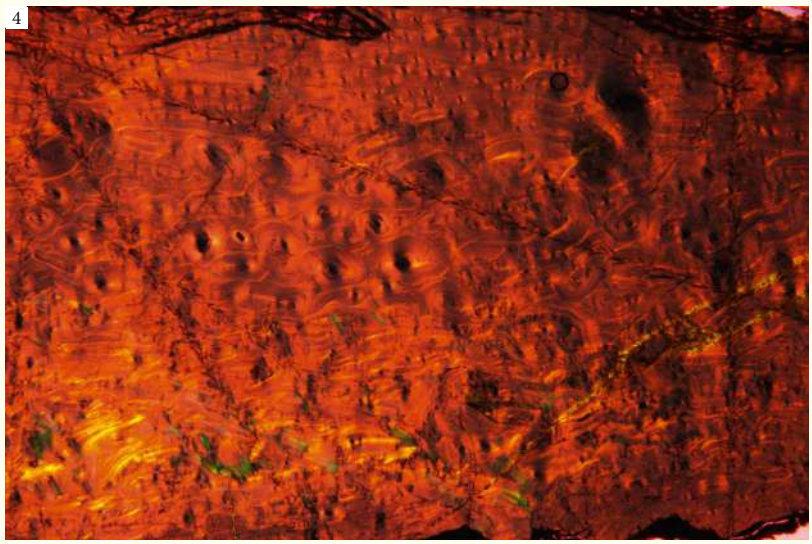


5

1. This artist's impression shows the possible appearance of an adult and two juvenile *Tethyshadros insularis* in a typical scene from the Cretaceous around 80 million years ago in their native Europe.

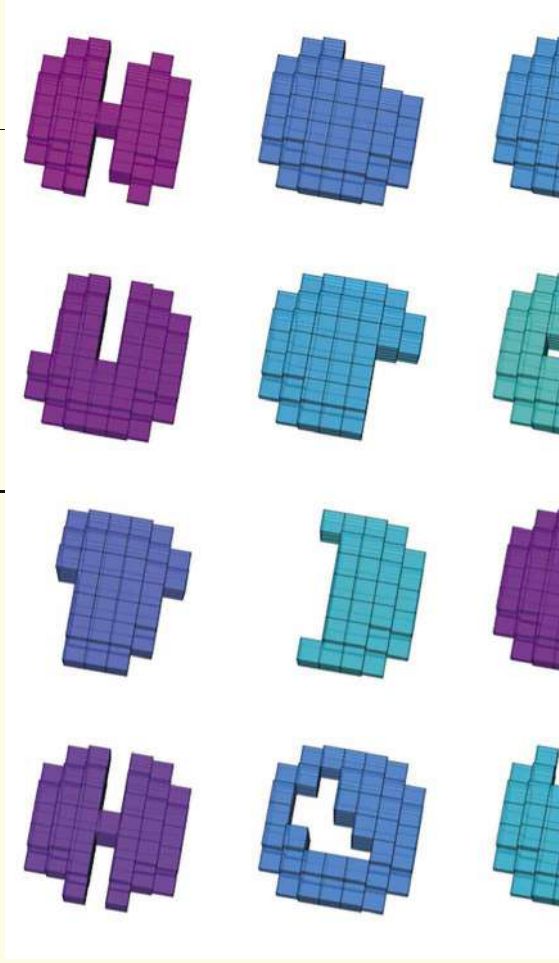
2. This outstandingly preserved adult *T. insularis* skeleton was named Bruno by the team. Bruno is one of the biggest and most well-preserved dinosaur remains ever discovered in Italy and is the team's star find.

3. The team of palaeontologists worked diligently at Villaggio del Pescatore, which is a palaeontological site, to painstakingly extract the fossils from the rock. The unique fossils collected from the site have now been put on display in the Museo Civico di Storia Naturale in Trieste.

4. This microscopic image shows the bones of one specimen named Antonio. If you look closely, you can clearly see the bone cells, which appear as black, circled dots. The fossilised bone tissues were analysed to establish the relative age of the dinosaur skeletons at the time of their death. The scientists determined that Antonio was likely to be an immature individual, while Bruno appeared to be older, but still probably growing.

5. The skull of Bruno is so beautifully preserved that you can easily make out details such as the eye socket, jawbone, brain cavity and teeth.

SAM KRIEGMAN
Roboticist



Horizons

Living robots capable of self-replication created in US lab

Sam Kriegman tells us about Pac-Man-shaped 'xenobots' made from frog cells that could one day lead to breakthroughs in medicine

HOW DID THIS PROJECT START OUT?

This project started as a collaboration between developmental biologists and roboticists. Our goal was to learn about how animals grow and regenerate by building robots with similar abilities. We made our first robots out of silicone rubber, which could change shape and volume to mimic growth. From there, we simply followed the scientific questions we found to be the most interesting, and our curiosity led us to the idea of building robots out of biological cells. Specifically, cells from the African clawed frog *Xenopus laevis*. Hence their nickname, xenobots.

YOU FIRST DESIGNED THE SHAPES OF THE XENOBOTS USING A COMPUTER SIMULATION, DIDN'T YOU?

That's correct, I built a simulation that tries to predict how cells will behave when arranged into different structures. If you look inside the computer simulation you'll see a virtual Petri dish containing virtual xenobots, each with its own design and unique behaviour. We run an evolutionary process of trial and error inside the simulation to find good xenobot designs. Often the computer comes up with simple, efficient solutions that humans fail to see. It's entirely possible that human cognitive limits and biases will prevent us from ever manually designing truly useful xenobots. But with computer software designing xenobots for us, the sky's the limit.

WHY DID YOU USE FROG CELLS?

We chose frog cells because that's what we had in the lab. These frogs lay thousands of eggs at a time, almost none of which survive in the wild. When the frogs' eggs were just one day old, we borrowed a few to make xenobots. There's nothing much inside the egg at this point, it's just a ball of mush – stem cells yet to take their form. There aren't any neurons or sense organs present, so we feel that this is an ethically responsible way to get our building materials.

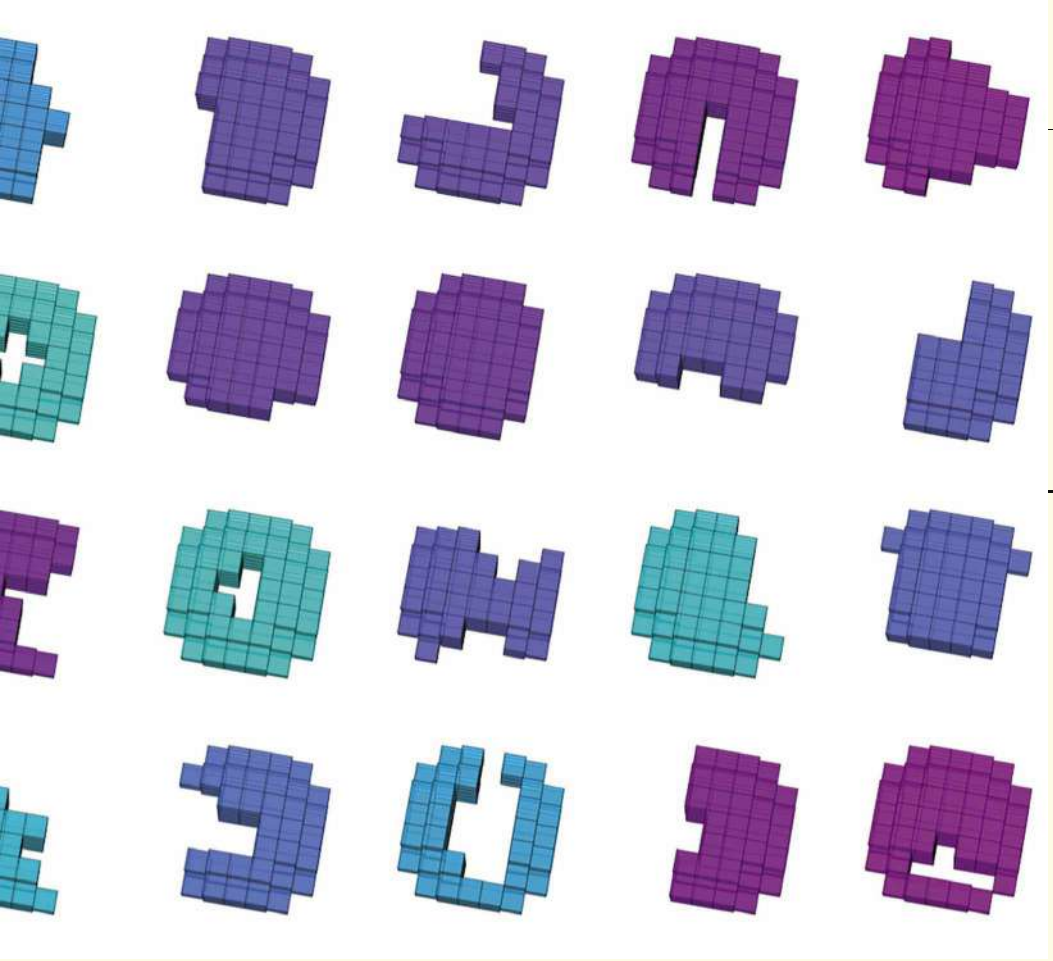
We steered the development of these cells into just two kinds of tissue – heart muscle and skin – because that's enough to create simple xenobots. For example, the very first xenobots we made could walk using heart cells, which contract and expand in volume like a piston, pushing the xenobot along the bottom of its dish. Our newest xenobots are made entirely of skin tissue that is covered in patches of small hairs called cilia. These hairs beat back and forth like flexible oars to propel the xenobot forward. One of the nice properties of frog cells is that they are self-powered: they come preloaded with energy, similar to the yolk of a chicken egg, which keeps them going for weeks without needing to be recharged or fed.

HOW DID YOU THEN PRODUCE THE XENOBOTS USING THE CELLS?

Anyone with a steady hand can build a xenobot by following the instructions detailed in our published studies. All you really need is a microscope, sharp forceps, frog eggs, salt water and a Petri dish. First, we harvest specific cells from one-day-old frog eggs. If we bring enough of these cells into contact with each other they will stick together and compact into a sphere. We can then carve out the computer-designed body shape by using sharpened forceps and a microcautery device that slightly burns the tissue so that it holds the desired shape. The resulting xenobot is less than a millimetre across, which is smaller than a grain of sand but visible to the naked eye as a speck.

WHAT WAS IT LIKE TO GO FROM THE COMPUTER SIMULATIONS TO SEEING THE LIVING XENOBOTS?

Every child dreams of building something out of Lego or Play-Doh



Computer simulations developed these xenobot shapes, which were then produced using frog cells

DOUGLAS BLACKISTON/ SAM KRIEGMAN

"Maybe in the future we will ingest xenobots as vehicles for drug delivery"

that magically becomes a walking, talking creature. So many books and movies explore this idea. The snowman in the movie *Frozen*, *The Gingerbread Man*, *Pinocchio,* various stories in mythology… We have this fascination that dates back to ancient literature about bringing inanimate objects to life. Every xenobot starts out as digital computer bits – a virtual creature inside a video game. If it exhibits interesting behaviours in the video game, we literally bring those computer bits to life. How cool is that?

SO THEN YOU FOUND THAT THESE XENOBOTS COULD MANUFACTURE COPIES OF ONE ANOTHER?

I think that is an excellent description of what's going on. We might say that they're reproducing, but reproduction in nature implies growth from a seed or an egg or a fragment of the parent. We found that if we sprinkled loose stem cells into a dish containing xenobots, the xenobots would push the stem cells into piles. Piles containing at least 50 cells developed into xenobot children. When we placed the children into a new dish, they acted just like their parents – they moved around and pushed loose cells into piles that developed into grandchildren. Grandchildren then build great-grandchildren, and so on. I understand that this process might sound like a party trick, but I believe it is an important scientific discovery – it's a previously unknown form of self-replication in biology that raises all kinds of new questions.

HOW DID YOU MAKE THEM REPLICATE IN THIS WAY?

Well, you can't plug a USB cable into a xenobot yet. But we can programme them in a sense by designing the parents' body shapes. As you might expect, some shapes are better at building piles than other shapes. As the xenobots' ability to replicate is tied to their ability to shovel cells into more and larger piles, better shovels are better replicators. The best replicator we know of is surprisingly simple – it looks like Pac-Man from the 1980s arcade game – a circular body with a single mouth cut out of its side.

ARE THERE ANY FUTURE APPLICATIONS THAT YOU'RE THINKING OF?

Given what we know about xenobots – that they are self-powered, biodegradable, very small, and aquatic – it's conceivable that they might have future underwater applications, perhaps cleaning up microplastics or other particles from lakes. They could also have medical applications further down the line. You definitely do not want to inject frog cells into your body. But we could, in principle, make xenobots out of human cells instead of frog cells. If we do that, then maybe someday in the future we will ingest xenobots as vehicles for intelligent drug delivery.

Of course, creating useful microrobotic medical devices is no easy task. If the robots look in any way like foreign invaders, they will trigger an immune response and the body will try to eliminate them. Think of an organ transplant that's going to save a patient's life, but their body rejects it anyway – this is a major problem in medicine. We can imagine a solution in which bespoke robots are created out of the human patient's own cells. That way the body will recognise the robots as part of the team and allow them to do their job. We're nowhere near this yet, but we've only been making xenobots for three years and they can already do some amazing things. Who knows where we'll be in 10 or 20 years. **SF**

SAM KRIEGMAN
Sam is a postdoctoral fellow at Harvard University and Tufts University.

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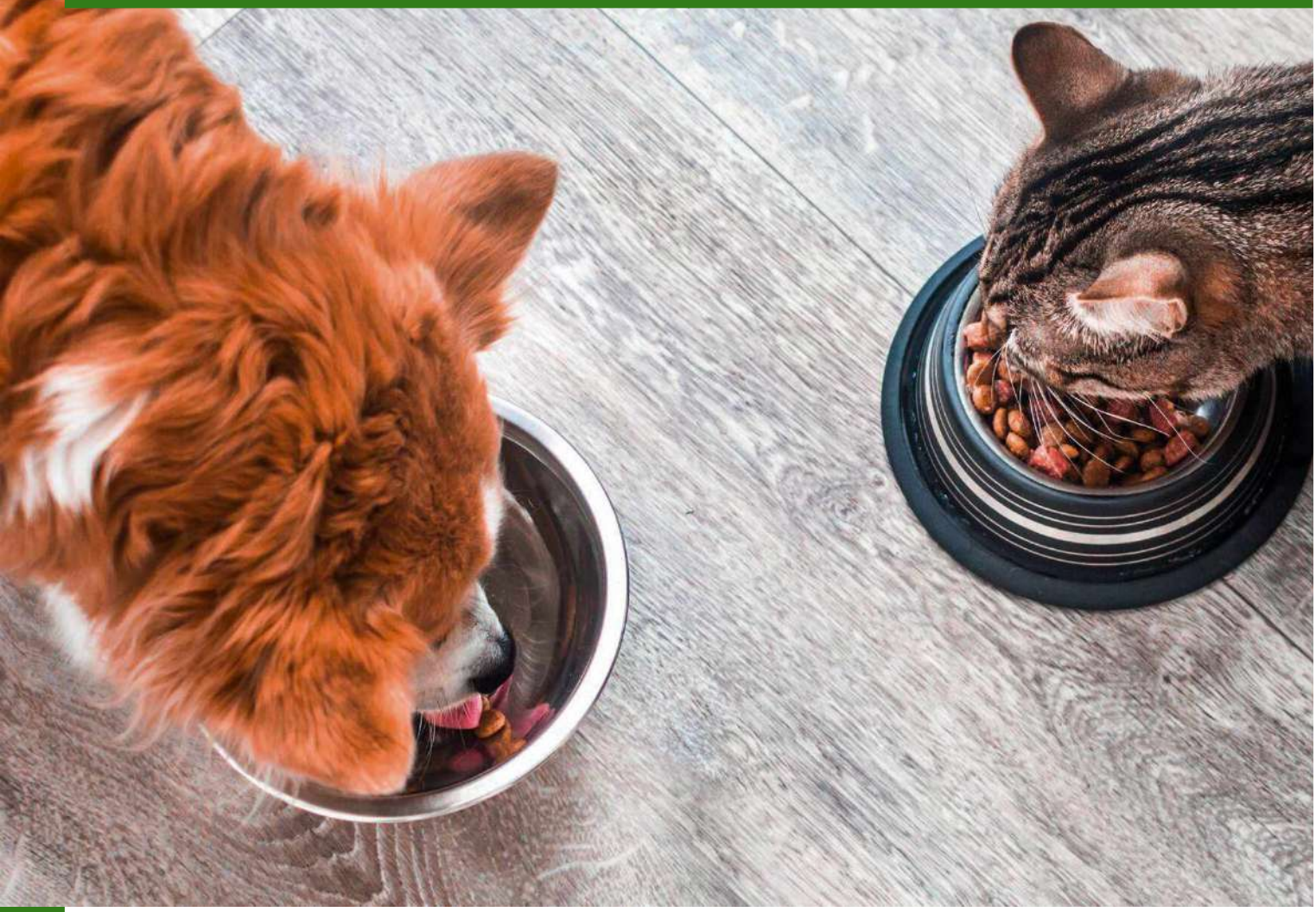
REALITY CHECK

SCIENCE BEHIND THE HEADLINES

CO_2 pawprints | Omicron variant | Havana syndrome



REVIEW

ANIMAL EMISSIONS: HOW BIG IS MY PET'S CARBON PAWPRINT AND WHAT CAN I DO TO MINIMISE IT?

Globally, pets chomp their way through about 20 per cent of the planet's meat and fish. Could Fido and Mr Tibbles adopt a more carbon-friendly lifestyle?

"How about providing edible toys for your dog or recyclable wooden 'trees' for your cats to climb on?"

BBC *Visit the BBC's* Reality Check *website at* ***bit.ly/reality_check_*** *or follow them on Twitter* ***@BBCRealityCheck***

WOULD IT BE BETTER IF WE FED OUR CATS AND DOGS A VEGGIE DIET?

Cats and dogs get more of their protein from meat and fish than we do. In the US alone, they account for about a quarter of all the calories consumed from animal products, emitting the CO_2 equivalent of around 13 million cars through livestock production, according to a 2017 study. Our pets would certainly be more environmentally friendly if they went plant-based, but can we make that choice for any species that has different dietary needs to us?

Domestic cats are obligate carnivores – they need the nutrients in meat to survive. Take the amino acid taurine, for example. Without it, cats develop heart problems and go blind. Though such essential nutrients can be given as supplements along with plant-based meals, there's intense debate between animal experts and vegetarians about whether, overall, these are adequate for cats' needs.

Dogs, on the other hand, seem better adapted to an omnivorous lifestyle and are capable of thriving on diets containing higher quantities of grains and veg. Though that doesn't mean we can simply cut out their protein.

One sustainable alternative is insect-based food from companies that sell high-protein dog and cat food pellets made from ground-up fly larvae. However, these foods tend to be expensive and may not be entirely carbon neutral as the insects are often shipped in from Europe, but with all the hype around insect farming, there may soon be more local suppliers.

And it's not just about the carbon emissions. Enforcing a vegan lifestyle on your cat, for example, could lead them to take their frustrations out on the local wildlife, damaging bird and rodent populations further. Research published in the journal *Nature* suggests US cats already kill between one and four billion birds a year, plus between 6 and 22 billion small mammals – a source of much anguish for wildlife lovers.

WHAT ARE THE MOST ECO-FRIENDLY WAYS TO ENTERTAIN OUR FURRY FRIENDS?

We should also think about all those chewed-up plastic pet toys that will find their way into landfill, and the steady stream of grooming products washing into the waterways from pet parlours. Humans, of course, use much larger quantities of plastics and water-polluting chemicals than our pets ever will, but if we're committed to sustainable living, then we can't ignore what we provide for our pets either.

If you're a conscientious pet owner, there are plenty of ways to reduce your pet's impact on the environment. How about providing edible toys for your dog or recyclable wooden 'trees' for cats to climb on? Do some research on your dog-grooming brands and switch to eco-friendly products. And stick to local green spaces for walks rather than driving to the beach or a far-flung beauty spot.

WHAT ABOUT ALL THE POO?

The 163 million dogs and cats in the US alone produce as much poo as around 90 million Americans, the 2017 study found. That's a ➤

BELOW Their size, lifespan and diet suggests tortoises make a very planet-friendly pet

ALAMY, SHUTTERSTOCK

huge amount of waste filling up dog waste bins and litter trays.

More recently, German researchers tried to estimate the climate change impact of just one dog over its lifetime and came up with a figure of around 7 per cent of the impact of an average person living in the EU. As part of their analysis, they tried to understand the impacts of dog litter when it was picked up in small plastic bags and collected by waste services, compared to when it was left on the street or in a park. They found that the climate change impact of dog poo was low, as long as all of it was picked up by owners and collected from dog waste bins by collection trucks on their normal routes, rather than having to be cleaned up from parks and streets on a poo-by-poo basis.

Bottom line: at least if you have a dog, you can pick up their waste, so do it. Though it's much harder to stop your cat making a mess in your neighbour's petunias…

I DON'T HAVE A PET, BUT I'M THINKING ABOUT GETTING ONE. WHAT'S THE GREENEST OPTION?

Um, a frog? (Only joking.) Actually, in terms of pet food, small animals like amphibians, reptiles and spiders are generally thought of as better options for the environment as they eat less, but they do consume energy in other ways, such as through heaters, or water filters for aquariums.

Money.co.uk recently compiled an 'Eco Pets League', in which large dogs scored worst, closely followed by ponies, horses and other sizes of dogs. The results were based on assigning points out of five for eco-friendliness across a series of categories from food and faeces, to heating/lighting and accessories. It's not a scientifically rigorous method, but it does give us some idea. Cats, fish and reptiles fared slightly better than our canine companions, but top of the leader board? The humble tortoise, which scored well across the categories and got bonus points for having a low impact across a long lifespan.

If a tortoise isn't the cuddly ball of fluff you're looking for, then the best you can do is to choose an animal that suits your lifestyle and try to be a responsible human for the sake of your pet, but also your planet.

by HAYLEY BENNETT

Hayley is a science writer based in Bristol, UK.

ANALYSIS

OMICRON VARIANT: HOW WORRIED SHOULD WE BE ABOUT IT?

Research has started to emerge on the latest variant of COVID. How concerned should we be about it, and what makes it different from previous variants?

Since we first heard about Omicron, the variant has been found in many countries around the world where it is driving the most dramatic spike in COVID-19 cases we have yet seen. In the UK, there were over 30,000 new cases a day in the one-week period from 14 December. On 22 December, cases were nearly double the previous peak seen in January 2021, and Omicron was the dominant variant. Similar trends

GETTY IMAGES

ABOVE People should continue with measures to prevent the spread of COVID-19, as the booster rollout alone is not enough to keep variants at bay

have also been seen in many other countries after the arrival of Omicron.

The four biggest questions surrounding Omicron are: is it more transmissible, is it more immune evading, does it cause different disease and do we need to do anything different to stop it. We do not have definitive answers to most of these questions, as we are still learning about the variant; however, several studies have recently been published as non-peer-reviewed pre-prints that may help to provide some answers.

The rapid spread of Omicron and the associated spike in COVID-19 cases in many countries suggests that the variant may be more transmissible. This concept is supported by pre-prints that show that Omicron is more infectious and has a shorter incubation period (the time between infection and the start of being contagious) than the Delta variant. However, the rapid rise in Omicron cases may also be due to its ability to evade the protection of vaccine- or infection-induced immunity.

Recent research from South Africa that has not yet been peer reviewed suggests that Omicron may be more immune-evading than Delta, with increased risks of reinfection. This is beginning to be confirmed with laboratory experiments that have shown low to virtually no protection against infection with two vaccine doses. Protection was somewhat restored in people that had an mRNA vaccine booster, though breakthrough infections of boosted individuals have been reported. Imperial College London has modelled the vaccine efficacy of two doses of AstraZeneca as between 0 to 20 per cent, rising to 55 to 80 per cent after a third dose.

Both Pfizer and Moderna have stated that two doses of their vaccines are significantly less effective against Omicron. Although a third dose was expected to increase protection, even two doses will likely still provide some protection against severe disease. There is also good evidence emerging that Omicron can evade immunity from a previous infection, even if that previous infection was with Delta or Beta, though it is not known if an Omicron infection would protect against a subsequent Delta infection. Modelling from Imperial College London estimates that Omicron is associated with a 5.41-fold increased risk of reinfection, compared to Delta.

Part of the reason for this immune evasion and possible increase in transmissibility is the large number of mutations Omicron has. Some mutations in the virus's spike protein are known to affect virus transmissibility and immune evasion. However, many are wondering if some of these mutations in Omicron have changed the severity of COVID-19 disease. Recent non-peer-reviewed research suggests that the variant may change where in the body it grows best, with Omicron showing less replication in the lungs than Delta but much higher replication in the bronchi (the tubes that carry air from the trachea to the lungs). It is possible that if Omicron does not replicate as much in the lungs, then it might cause less severe disease.

MILDER SYMPTOMS?

An early report from South Africa has suggested the variant may produce more mild symptoms, a conclusion that has been met with much debate. Recent non-peer-reviewed research from South Africa looked at over 160,000 COVID-19 cases and found that Omicron infections were less likely to result in hospitalisation or severe disease in adults, compared to Delta. However, the authors note that this may be because many of the Omicron cases are reinfections, with immunity from previous infections conferring some protection.

Similar trends are now being observed in the UK, with both Imperial College London and the University of Edinburgh finding a reduction in the risks of hospitalisation with Omicron compared to Delta. In children, data from South Africa shows an increase

in paediatric hospitalisations with Omicron. In Scotland there also appears to be a slight increase in the rate of hospitalisations in children with Omicron. None of this data has yet been peer reviewed and our full understanding of the clinical course of the disease and its severity will likely change as new and more full information becomes available over the coming weeks.

Even if the severity of Omicron is lower than that of Delta, we know the variant can still cause severe and fatal illness. With the current rapid rise in cases, even a small rate of severe infections could result in a large number of hospitalisations that threaten overburdening the NHS.

In addition, it is expected that Omicron infections will still result in approximately 12 per cent of cases going on to develop the long-term debilitating symptoms of long COVID, for both adults and children. At the current level of over 200,000 COVID-19 cases per day in the UK (as of 4 January 2022), that would be 24,000 new cases of long COVID every day. This would be on top of the estimated 1.9 per cent of the UK population that is already suffering from long COVID. Even a 'mild' version of Omicron could result in significant impacts to health, the NHS and the economy, and requires our immediate action to protect both adults and children.

However, our actions to address Omicron cannot rely solely on vaccine boosters, as vaccine uptake has lagged and the efficacy of the boosters in stopping infections is likely to be lower than we were seeing for Delta (though widespread uptake of the boosters will help reduce transmission and severe infections). As the booster rollout is carried out, it is important that both adults and children still continue with preventative measures that remain highly effective, even for Omicron.

It is likely that most testing methods (PCR and rapid antigen tests) will still detect Omicron. Masking, distancing, ventilation, testing, isolation, quarantine and vaccination have all been proven to reduce virus transmission. Together, the use of these measures can control the spread of Omicron, reduce hospitalisations and long COVID and minimise the burden on the NHS, without requiring a lockdown.

Regardless, it is important to remember that Omicron will not be the last variant. As long as we continue to have COVID-19 infections around the world, we will continue to have virus evolution. Thus, there is a need to continue taking precautions while ensuring global vaccine availability.

by **DR JEREMY ROSSMAN**

Jeremy is a senior lecturer in virology and president of Research-Aid Networks at the University of Kent. His research focuses on the process of infectious disease outbreaks, and he has contributed to studies published in journals including PLoS Pathogens, Bioinformatics *and* Cell.

COMMENT

HAVANA SYNDROME: WHAT'S CAUSING THE MYSTERIOUS ILLNESS?

Some have blamed top-secret weapons, but the condition could be all in the mind

In December 2021, a former FBI agent previously posted to Guangzhou in China began legal proceedings against the US government. The agent claimed the US Secretary of State and the Department of State hadn't taken the situation seriously enough when, while in Guangzhou, the agent and his family had begun experiencing sudden headaches, dizziness, nosebleeds, memory loss and nausea.

It was the latest development in a saga that began to unfold in 2016 when dozens of staff at the US embassy in Cuba started describing similar symptoms, often accompanied by an ear-splitting sound and facial pain.

Depending on who you ask, so-called 'Havana syndrome' – which has reportedly affected over 200 US staff in Cuba, China, Germany, Austria, Russia and Serbia (there was also a suspected case in Washington) – is caused by a Russian sonic- or microwave-based weapon, or a textbook case of mass psychogenic illness.

The Russians deny having an acoustic weapon that can target the brain. But in 2020, the US National Academies of Sciences, Engineering, and Medicine published a report in which they concluded that "many of the distinctive and acute signs, symptoms, and observations" described by US employees are "consistent with the effects of directed, pulsed radio frequency energy". And in November 2021, the FBI admitted to having issued a formal warning to its staff about what it calls "anomalous health incidents".

There are reasons for being sceptical about the weapon theory, though. Security experts have said that it's unlikely Russia would have been able to develop some as-yet-unidentified technology without the West finding out. And neurological experts have pointed out that it's implausible that a sonic device could selectively target the brain.

Meanwhile, recordings said to be of the sounds heard in Cuba (and blamed for the symptoms) have been identified by researchers at the University of California, Berkeley, as most likely being the mating call of a Caribbean cricket. And in 2018, a group of

GETTY IMAGES, ALAMY

“At the heart of this phenomenon is the ‘nocebo e ect’, which is the harmful reverse of the ‘placebo e ect’. In this case, the mere belief that something is harmful can provoke real symptoms”

ABOVE If correctly primed, your mind can have an effect on how well, or not, you feel

researchers at the University of Pennsylvania reported that brain scans they’d performed on 21 former Cuba-based US staff who’d experienced the neurological symptoms showed no significant abnormalities.

When physical symptoms are experienced in the absence of any identifiable physical cause, such as a virus, and especially when the symptoms show signs of contagiousness between people who are in close contact, then one plausible explanation is mass psychogenic illness. This means the ultimate cause of the illness is people’s beliefs, which then ‘infect’ others, potentially leading to a mass outbreak. Some experts argue, controversially, that this is the most likely cause of Havana Syndrome.

Mass psychogenic illness has a few key components. The first is that a set of similar health symptoms emerges in a group of people in close contact. The second is that it often occurs in a context of intense stress or anxiety. And finally, there must be an absence of any known ongoing organic cause, such as a virus, bacteria, poison or cutting-edge sonic weaponry.

It’s worth noting that the initiator of a psychogenic outbreak could have a physical illness. But to meet the criteria for mass psychogenic illness, the people subsequently affected must not have been exposed to that cause, only to the idea of the symptoms.

At the heart of this phenomenon is the ‘nocebo effect’, which is the harmful reverse of the ‘placebo effect’. In this case, the mere belief that something is harmful can provoke real symptoms, just as positive beliefs about a placebo pill can induce real medical benefits. That word ‘real’ is important. Just because the causes of a syndrome are psychological does not mean the suffering and symptoms are not real.

There are countless confirmed cases of mass psychogenic illness in the medical literature. Here’s just one: imagine being at school and suddenly a rising number of your classmates report smelling a strange aroma, followed by a feeling of intense nausea. As fears grow, you too begin to feel discomfort in your stomach and, before you know it, you’re sick too.

It is hard to believe it’s all in the mind and that there’s not some kind of a chemical spill or gas leak. Yet this is exactly what happened at a South Yorkshire school in 2006 when more than 30 pupils and a teaching assistant were suddenly taken ill. No leak was found and all of the pupils that were rushed to hospital were discharged within a few hours.

It’s not currently possible to know for sure whether Havana Syndrome is a mass psychogenic illness, but it does fit some or all of the criteria. Many of the affected agents have been operating in stressful environments. They’ve been in close contact with each other, exposed to the idea of the symptoms and the dread that they might be affected. In the absence of any apparent physical explanation, and with the sonic weapon being purely theoretical and unproven at this point, then a psychological cause seems plausible. **SF**

by **DR CHRISTIAN JARRETT**

Christian is a cognitive neuroscientist, science writer and the author of Great Myths Of The Brain *and* Be Who You Want.

ff A camera that lets you print on the move, or send pictures to your phone p40

INNOVATIONS

PREPARE YOURSELF FOR TOMORROW

The tiny camera, the size of a grain of salt, is crammed with more than a million tiny posts that effectively channel light towards a sensor

DRUG DELIVERERS
A lot of research into nanotechnology in medicine focuses on the delivery of drugs. Researchers at Purdue University are testing out a wearable patch that uses silicon nanoneedles to deliver chemotherapy to the skin to treat melanomas.

WOUND HEALERS
Through the use of nanogenerators, researchers at the University of Wisconsin have found a way to make a bandage that applies electrical pulses to the site of a wound, speeding up the healing process. The method uses the body's own motions to supply the energy needed.

CANCER DETECTORS
Northwestern University scientists are working on a method of detecting cancer cells in the bloodstream. Called NanoFlares, they are designed to bind to genetic targets in cancer cells and light up when that target is found.

OPTICS

Scientists build working camera the size of a grain of salt

Honey, I shrunk the camera... to revolutionise surgery

Ever wanted to live out your own *Innerspace* experience? This camera is roughly the size of a grain of salt and could one day find itself working its way around your digestive system to give doctors a clearer picture of your health.

Built by researchers at Princeton University and the University of Washington, the camera is able to pump out clear, full-coloured images equivalent to what you would usually see from a camera 500,000 times the size!

To build a working camera at this scale, the scientists had to completely reimagine the tech that you would find inside a camera. "In order to shrink down the size of the camera, you really have to look at the optics," says Felix Heide, the study's senior author. "If you look at other pieces of a camera, that being the sensor and the electronics, they have already been miniaturised over the last decade. The optical systems haven't really been designed very differently since the days of Gauss [who worked on lenses in the 1800s]."

"THERE'S POTENTIAL OF BRINGING THESE ULTRA-SMALL CAMERAS INSIDE THE HUMAN BODY TO DO ENDOSCOPY"

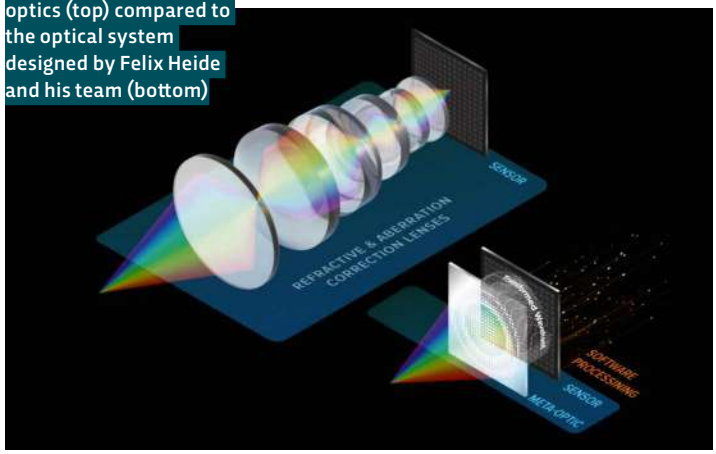
Instead of the usual array of curved glass pieces used in most camera optics – which we know as lenses – this tiny device makes use of metasurface technology, cramming an incredible 1.6 million cylindrical posts onto a surface just half a millimetre wide. These posts are absolutely tiny, each roughly the size of the human immunodeficiency virus (HIV).

The posts effectively channel incoming light towards a sensor. A machine-learning algorithm then makes sense of the pattern of light hitting the surface of the sensor. In the past, ultracompact lenses have produced blurry images with a small field of view and a limited colour spectrum. But Heide and his team were able to use simulations to train the algorithm to create a clear picture from the data collected.

It's tiny, complicated and surprisingly high-definition, but other than being an impressive display of science, what could this camera be used for? "There's potential of bringing these ultra-small cameras inside the human body to do endoscopy on a smaller scale. That's one of the areas we're really pushing forward," Heide explains. "Then a completely different area we're looking into is space imagery. How can we bring down the size of a telescope, for example, to something much lighter so you don't have to bring these massive optics into space."

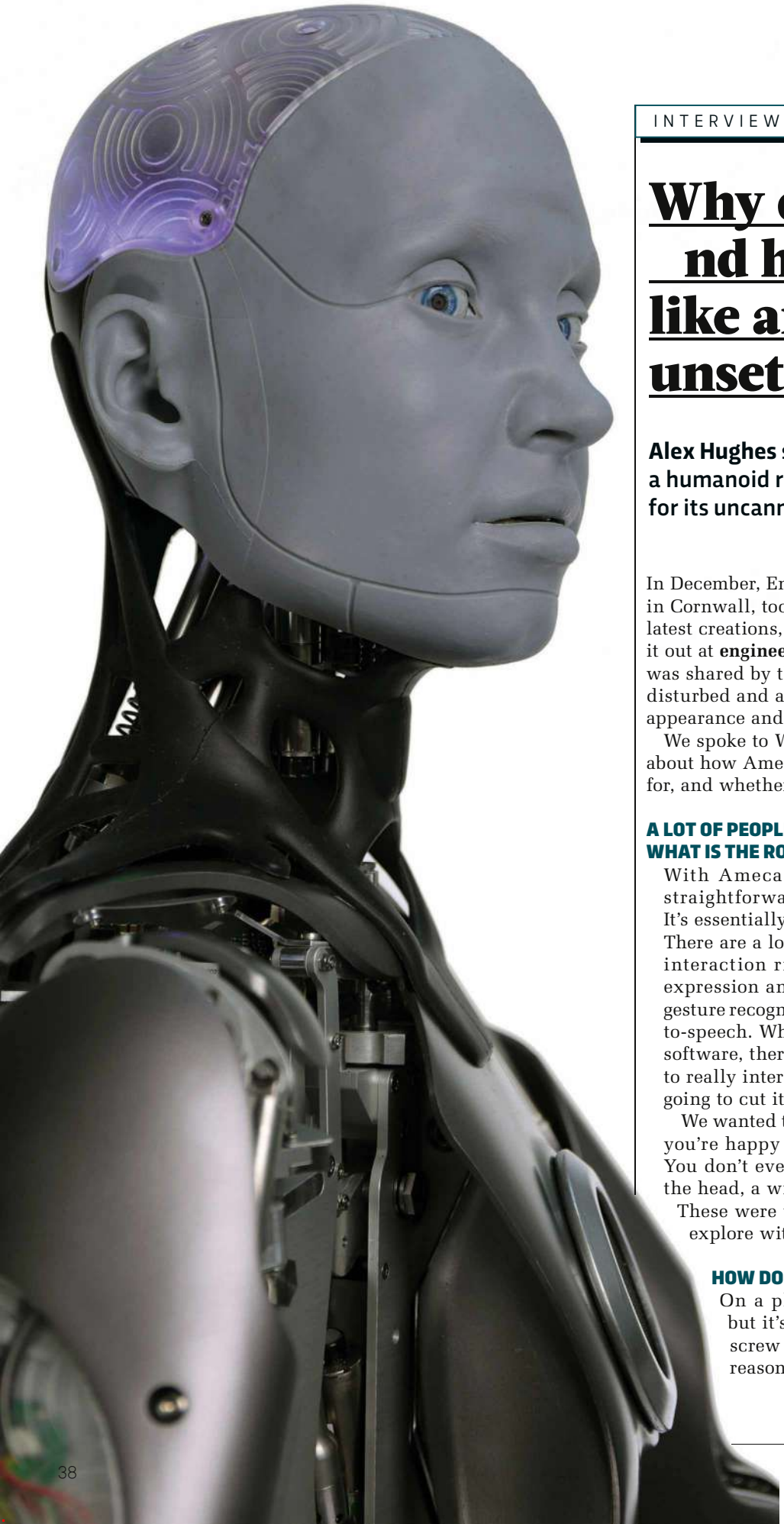
Another possible use is in smartphones. With such tiny devices, you could pack hundreds of cameras into one phone, with them all working together for a superior performance.

For now, a lot of this is very much theoretical and there are obstacles that still need to be overcome. Our biggest question remains around how the images will be saved... the idea of a tiny SD card joining the camera on an intestinal journey comes to mind!



Conventional compound optics (top) compared to the optical system designed by Felix Heide and his team (bottom)

PRINCETON UNIVERSITY X2, PURDUE UNIVERSITY/CHI HWAN LEE, NORTHWESTERN UNIVERSITY, SAM MILLION-WEAVER



INTERVIEW

Why do we nd human-like androids so unsettling?

Alex Hughes spoke to the creator of Ameca, a humanoid robot that's been going viral online for its uncanny facial expressions

In December, Engineered Arts, a robotics company based in Cornwall, took Twitter by storm with a video of one its latest creations, a humanoid robot named Ameca (check it out at **engineeredarts.co.uk/robot/ameca/**). The video was shared by thousands of people on Twitter, who were disturbed and amazed in equal measure by its human appearance and lifelike expressions.

We spoke to Will Jackson, CEO of Engineered Arts, about how Ameca was made, what the robot will be used for, and whether he finds his own creation unsettling.

A LOT OF PEOPLE SAW THE VIDEO OF AMECA ONLINE, BUT WHAT IS THE ROBOT FOR?

With Ameca, we wanted to create an intuitive and straightforward way to communicate with a machine. It's essentially a humanoid designed as a platform for AI. There are a lot of people working on software for human interaction right now, things like facial recognition, expression and estimation, and then there's things like gesture recognition, speech recognition and generated text-to-speech. While there are lots of people working on the software, there's very little hardware. If you want people to really interact with an AI, a screen and keyboard isn't going to cut it.

We wanted to build a machine that, if you smile, knows you're happy and if you frown, knows you disapprove. You don't even have to speak to communicate; a nod of the head, a wink, or a smile is worth a thousand words. These were the kind of interactions that we wanted to explore with Ameca.

HOW DOES AMECA WORK?

On a physical level, there are loads of motors, but it's quite a novel design. We use a lot of ball-screw actuators that approximate human muscles reasonably well. You'll notice in the videos that the

ENGINEERED ARTS X3

movement is very fluid because we've spent a lot of time getting that right.

On the software side, we have a complete software stack that has everything from motor control all the way up through to AI functions like face and speech recognition. That said, Ameca is not a sentient robot. People tend to project their own idea of what a robot is: if they see it behave in a certain way, they make assumptions because those are human-type behaviours that are usually driven by a human level of sentience, but that's absolutely not true.

What you're looking at is some code executing, and some of it can be quite simple. But the illusion can be engaging and quite powerful.

DO THE ROBOTS EVER FEEL CREEPY TO YOU?

Yeah, you get caught off-guard. They do things that you don't quite expect. They're programmed to make eye contact, and sometimes when they give you a funny look, you can't help attributing some sort of thought process to that.

We've left a lot of the mechanics exposed with Ameca, and that was an attempt to get away from what's called the Uncanny Valley. That's a kind of graph of robot appearance vs acceptability. If you get too close to being human, the graph dips into the valley, which means it's creepy: you don't like it because it's close to resembling a person, but not quite perfect.

Boston Dynamics [a US-based robotics company] has the same thing with its robot dog. It has no head and is obviously mechanical, but it moves just like a dog. There was one video where somebody kicks the robot. There's something deep down inside us that recognises when something's alive from the way it moves, and it's really hard to override that association of biological motion equalling a living thing.

BOTH YOU AND BOSTON DYNAMICS OFTEN GO VIRAL WITH YOUR VIDEOS, WHAT DO YOU THINK FASCINATES PEOPLE SO MUCH ABOUT THEM?

For Boston Dynamics, their work is about a robot getting from point A to point B. We're more focused on human interaction. However, when their machines start to move like living things, they fall into the Uncanny Valley. I think that's what takes the videos viral. There's always that Terminator scenario that people imagine, thinking this will spell the end of the world, but I wouldn't worry too much about that. If an AI wanted to destroy us, it would not send a humanoid robot. It would just detonate some warheads, it would be a lot quicker to wipe us out than chasing us around with guns – that scenario just makes a good movie.

It's about this vision of self. It's like looking at yourself in the mirror and seeing this machine and wondering what's different between the two of you. Seeing something that moves and behaves like a human, I think, scratches at that and that's what makes these videos go viral.

FOR THE PEOPLE CONCERNED ABOUT ROBOTS, WHAT WOULD YOU SAY TO REASSURE THEM?

There are serious concerns around AI, but AI is not robots, so worry about the software and what you put in control of it. I wouldn't ever put a weapon system in the control of AI, that's a really terrible idea.

Do the military use humanoid robots in active service? Not as far as I know. Do they use drones to drop bombs? Yes, so worry about that. It's not something we're interested in as a company either, we've never actually done defence work.

The analogy I like to make is of C-3PO in the original *Star Wars* film. It's a friendly robot that's there as a translator, basically, for entertainment. When the two robots, R2-D2 and C-3PO, are captured and being resold, nobody wants to buy C-3PO because it's regarded as a useless robot. Everybody wants R2-D2, the little tin can thing with a dome head because he's seen as useful utility.

WILL JACKSON

Will Jackson is the founder and CEO of Engineered Arts. He started the company back in 2005 and since then, it has been at the forefront of humanoid robotics design. Now with a roster of realistic robots, he aims to revolutionise the way we interact with robots.

Ideas we like...

↓...a unique, modular action cam

Like most action cameras, DJI's new device is small, tough and captures surprisingly high-quality shots in fast-moving environments. Where the DJI Action 2 is slightly different to the competition is in its modular design. Thanks to some magnets, you can snap on a host of accessories, mounts and features. While DJI is making the most noise about tripods, head mounts and other pretty standard features, it's the add-ons like the macro lens, power module and microphone that have us pretty excited.

DJI Action 2
From £349, dji.com

↑ ...a modern-day analogue camera

Yes, instant cameras that can print out your photos immediately are still a thing. Fujifilm has been working overtime trying to keep them alive for decades now, bringing digital camera features to a distinctly analogue process. With the instax mini Evo, it feels like Fujifilm has cracked that code. The camera allows you to print on the move or send the photo to your phone. It includes 10 lens modes with 10 different filters, offering a total of up to 100 different combinations. At first glance, it looks just like a retro film camera, but on the back is a three-inch LCD display. UK pricing is yet to be announced.

instax mini Evo
£TBC, instax.com

→ ...a cyberpunk quadbike for kids

Last time Elon Musk got a crazy consumer tech idea, he decided to sell flamethrowers. Fortunately for everyone's eyebrows, his latest invention is just an expensive all-terrain vehicle, marketed at... kids? Modelled after Tesla's futuristic Cybertruck design (where is that anyway?), the Cyberquad features a steel frame, cushioned seat and LED light bars. It's powered by a lithium-ion battery with up to 24km (15 miles) of range and a top speed of 16km/h (10mph).

Tesla Cyberquad
$1,900 (£1,433 approx), shop.tesla.com

←...a minimalist speaker

We'll be honest, this speaker by Braun isn't anything unique. It doesn't have any crazy gimmicks or an out-there look, but that's what we like about it. With a clean and minimalist design, the LE02 is going to fit effortlessly in most homes. This mid-sized speaker is built with some smart audio features in mind, and pumps out a big, balanced sound. Like most speakers these days, LE02 comes with Google Assistant, multi-room pairing and EQ adjustments for when the audiophile in you needs to make some tweaks.

Braun LE02 speaker
£749, braun-audio.com

↑...high-de nition Zoom calls

What do you get when former members of Apple, Beats and Uber come together to design a webcam? The answer: something stylish, powerful, functional and... well... fairly expensive.

With the aim of being the 'first professional webcam', the Opal camera is making a big promise. Specifically designed for Apple Macs, it brings DSLR quality to a webcam while also pulling in intelligent noise cancellation and what can only be described as a hefty amount of microphones. Still in a reservation-only beta stage, it could be a while before you can get your hands on this camera. Let's just hope it can edit out a few of the chins we've gained over the pandemic.

Opal camera
$300 (£226 approx), opalcamera.com

↓...headphones with a unique charging feature

If you've ever been left with dead headphones on the train, Urbanista's new Los Angeles headphones could be just what you need in your life. Thanks to a solar cell material in the headband, these headphones charge themselves just by being out in the light, offering virtually infinite playtime. This isn't a one-trick pony either, as the headphones also include active noise cancellation, on-ear detection and most importantly, a well-made design and strong audio performance. While it sounds good in practice, the perpetually dark and gloomy weather of the UK could leave you needing a plan B...

Urbanista Los Angeles
£169, urbanista.com

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Science Focus
YOUR MYSTERIOUS BRAIN

JUST A FEW YEARS AGO, IT FELT LIKE FLYING CARS WERE STILL A DISTANT SCI-FI FUTURE WE COULD ONLY DREAM ABOUT. BUT INVESTMENT HAS INCREASED RAPIDLY, AND A NUMBER OF COMPANIES ARE NOW BUILDING AIR TAXIS TO MAKE OUR CITY JOURNEYS FASTER, EASIER AND CLEANER

WORDS: IAN TAYLOR

WELCOME TO YOUR

FUTURE COMMUTE

BOB MUMGAARD/CREATIVE COMMONS

It's hard to decide whether flying taxis are arriving very late or extremely early. On the one hand, the promise of airborne cabs zipping between skyscrapers has been a science fiction staple for decades. On the other, it wasn't long ago that air taxis were filed in the 'we'll see' folder of future technology, alongside hoverboards and hotels on the Moon.

But after years of wishful thinking, it's suddenly happening. Investment in advanced aerial mobility (as the sector is known) has more than tripled in the last year, and analysts at Morgan Stanley expect the global air taxi market to be worth £2.7tr by 2050.

Early or late, the future is en-route and will be coming in to land sooner than the majority of people realise. A number of companies around the world are currently preparing eVTOL vehicles (electric vertical take-off and landing vehicles), which could revolutionise the way we get around big cities.

Quiet, comfortable and carbon-free, eVTOLs promise to rise above congested roads, easing urban transport issues while getting passengers to their destinations in record time. Meanwhile, regulators on the ground are working hard to prepare the rules and infrastructure required to make this new form of transport feasible.

CHOCKS AWAY

Many developers believe their vehicles will be safety certified and cleared for take off by 2025, if not sooner. Boeing, Airbus and Hyundai are some of the familiar names building air taxis. Another is Joby, which bought Uber Elevate, the ride-sharing giant's foray into eVTOLs, in December 2020. Meanwhile, British firm Vertical claims to have the highest number of conditional pre-orders with the likes of Virgin Atlantic and American Airlines among the investors lining up for its VA-X4 vehicle (images on p51).

"It's going to be a quiet and pleasant, fast and efficient way of getting around," says Andrew Macmillan, director of infrastructure at Vertical. "[The VA-X4] allows you to travel 100-plus miles [160km] at 200mph [322km/h]. It takes off vertically and then transitions to fly horizontally, giving you that range."

The VA-X4 will carry four passengers and a pilot. In the rear, two pairs of people will sit facing each other like in the back of a London taxi. As a fare-payer, you can look out of the windows and chat with your fellow flyers without the need for ear protection or microphones. That's because, like the majority of eVTOLS, the VA-X4 flies using quiet electric rotors that, per journey, produce less carbon than a Tesla travelling the same distance on the roads below.

Air taxis are not exactly the flying cars promised by *The Jetsons*, *Blade Runner* and *Back To The Future*, however. Rather, it's electrified air travel scaled down to black cab proportions. It's Uber for the skies. Think helicopters without the emissions or the reliance on one main rotor.

ABOVE Airbus unveiled the NextGen version of its CityAirbus air taxi in 2021. Although still on the drawing board, a prototype is due to begin being tested in 2023

TOP RIGHT The VoloCity air taxi, seen here taking a demo flight over Singapore's Marina Bay in 2019, bore only a passing resemblance to the prototype that first flew in 2011

BOTTOM RIGHT Boeing's Passenger Air Vehicle (PAV) is an autonomous air taxi with a configuration that differs from the 'norm', relying on propellers that are not positioned on the wings

"MANY DEVELOPERS BELIEVE THEIR VEHICLES WILL BE SAFETY CERTIFIED AND CLEARED FOR TAKE OFF BY 2025"

ITER ORGANISATION X2, SHUTTERSTOCK

The Joby aircraft is expected to gain its air carrier certification from the Federal Aviation Administration in the US in 2022, and there are plans for it to be in service as an aerial ride-share service by 2024

"THIS IS, IN FACT, AVIATION – THE NEXT GENERATION OF IT: A QUIETER, CLEANER, MORE SUSTAINABLE AVIATION"

"Helicopters are amazing machines, but they're quite noisy, they're very expensive and they're quite dangerous as well," Macmillan says. "One of the reasons the VA-X4 is safe is that you've got eight rotors, all electric powered, and each of them has a separate motor. If you lose one, you don't lose the vehicle."

If eVTOLs are revolutionary in what they might do for urban transport, they're more evolutionary in terms of the underlying technology. Electric propulsion, super-efficient batteries and lightweight composites underpin air taxi design and all of it comes from technologies being developed in tandem sectors.

"I think we've been able to reap some of the benefits of what's been happening on the surface side of electric propulsion," says Clint Harper, urban air mobility fellow at Urban Movement Labs, a non-profit designed to help facilitate future transport solutions in Los Angeles. "The overall design of the aircraft, how they fly, how they stay in the air, you know, we're building off lessons that have been learnt over the last century of air travel."

The point is that eVTOLs are not flying cars at all. "This is, in fact, aviation – the next evolution of it: a quieter, cleaner, more sustainable aviation," says Harper's colleague, Sam Morrissey, executive director of Urban Movement Labs. "Once we reframe it back to aviation, I think people understand how and why we're going to see these new vehicles and this new technology as quickly as we're going to."

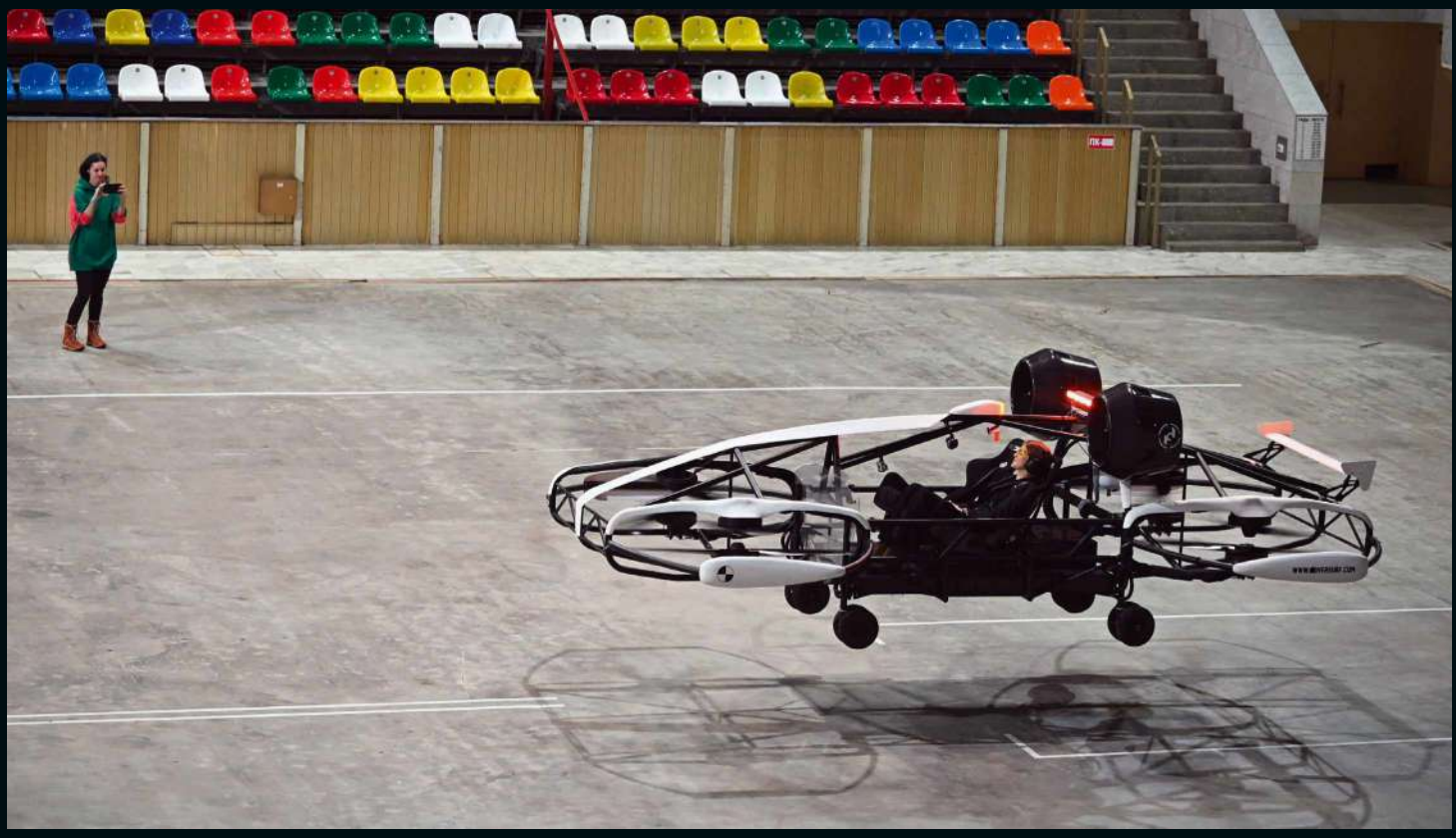
BEAT THE TRAFFIC

Urban Movement Labs is helping the city of Los Angeles prepare for the advent of eVTOLs. The famously horizontal city grew by sprawl and its freeways are known for traffic jams. Morrissey believes advanced air mobility could ease the problems on the ground and "make travel happen in a way that's not [currently] physically possible."

His example is travelling from downtown Los Angeles to Santa Monica, 15 miles [24km] away. "It's physically impossible to make that trip in under 30 minutes. But, say my child was in a hospital in Santa Monica, with this new technology I could make that journey in minutes."

Los Angeles isn't the only place that's preparing for flying taxis. São Paulo, Osaka and Singapore are some of the sprawling, densely populated, global cities at various stages of planning for advanced air mobility. Closer to home, Europe's first 'vertiport' – the name for eVTOL landing sites – is being built in France in time for the 2024 Paris Olympics. Vertiports have also been proposed for the UK, where a number of intercity eVTOL routes have already been planned.

Imagine travelling cross-country from Liverpool to Hull, or flying over water from South Wales to Cornwall, or Belfast to Glasgow. Even a seemingly pedestrian journey from Heathrow Airport to Cambridge takes



two hours or more by car or train. You could do it in 20 minutes in an air taxi.

In order for those journeys to become a reality, however, much more planning and infrastructure is required. eVTOLs may plug into existing air traffic control structures and communication frequencies, but regulators will need to develop new licensing and credentials standards. There's also the rather pressing question of where exactly air taxis will land and take off from.

Initially, they are likely to fly to and from existing airports and helipads, but they'll very soon need their own spaces within our cities, explains Harper. "Once we talk about integrating those into the urban fabric of the neighbourhoods or communities, there's a lot of things to think of," he adds. "It's going to take dedicated infrastructure, which includes recharging these vehicles, maintenance and servicing, and storing them overnight."

"FOR THOSE JOURNEYS TO BECOME A REALITY, HOWEVER, MUCH MORE PLANNING AND INFRASTRUCTURE IS NEEDED"

In science fiction, flying cars often dock on skyscrapers, but that's unlikely to be practical in the real world. Would you want to climb to the top floor of a tall building just to catch a taxi? Morrissey believes vertiports could instead be built on top of, or alongside, existing transport hubs so that passengers can connect from one mode to another. "We see this as integrating with the existing bus, rail and transit networks in places that are truly multimodal hubs," he says.

Planning is vital. In the past, new transportation technologies have come along and surprised society. "The steam locomotive was created and we had to build tracks and railroads. The bicycle and the internal combustion engine were invented and we had to build roads," says Morrissey. Even today's electric scooters caught governments and city planners napping, with the vehicles hitting roads before rules were drawn up to govern their usage.

There is reason to believe that advanced aerial mobility will be different, however. There is a (metaphorical) runway between now and the vehicles' launch, during which planners have time to work out how, where and why eVTOLs should fly. "I think, for the very first time in human history, we're able to develop a transportation system to serve a new mode of transportation before that mode of transportation

ABOVE 2021 saw the Russian company Hoversurf testing a prototype of the vehicle it hopes to develop into a drone air taxi

ABOVE RIGHT Two of the four passenger seats in Vertical's VA-X4 cabin

RIGHT An artist's impression showing Vertical's VA-X4 vehicle waiting for its next fare on top of a city-centre skyscraper

EUROFUSION CONSORTIUM, ELLE STARKMAN/PRINCETON PLASMA PHYSICS LABORATORY

exists," says Morrissey.

As well as flying taxis, eVTOLs could be used for search and rescue, transporting organs for transplant, as well as delivery and tourism. Estimates vary, but we could see hundreds or even thousands of them in the skies above the UK in the coming decades, with remotely piloted or even automated vehicles coming in time. However many there are, experts now agree that it's not a case of if, but when the technology will arrive.

"Safety certification is the tipping point," says Macmillan. "Once you start seeing that happen, then you know it's real because you'll just see them flying through the air." **SF**

by **IAN TAYLOR**
Ian is a freelance science writer, and former deputy editor of BBC Science Focus *magazine.*

AN END TO AGEING?

Eternal youth is the stuff of religion and mythology, but what if we could just have a bit more of it? What if there was a pill that could slow down the ravages of time, so that you could feel younger for longer. It sounds like snake oil, but there's a growing body of research that's betting on making it a reality

by DR HELEN PILCHER

Picture the scene. After a routine blood test, you visit your GP for the results. "It's all good," says the doctor reassuringly. "The only problem is that you're getting older." Then, with a flourish of the prescription pad, the doctor adds: "But I can help you with that. Take these tablets. They'll slow the ageing process and help you to stay healthy. Oh, and they might just make you live longer too."

A drug that extends your life, slows ageing and staves off the ravages of old age, including frailty and disease? It sounds too good to be true, and yet, an increasing weight of evidence suggests not just that these drugs are within reach, but that they may already be here. Some can be found on the shelves at your local health store, while others are drugs for conditions such as diabetes and cancer that are being repurposed. Animal studies have demonstrated their potential, and now clinical ➔

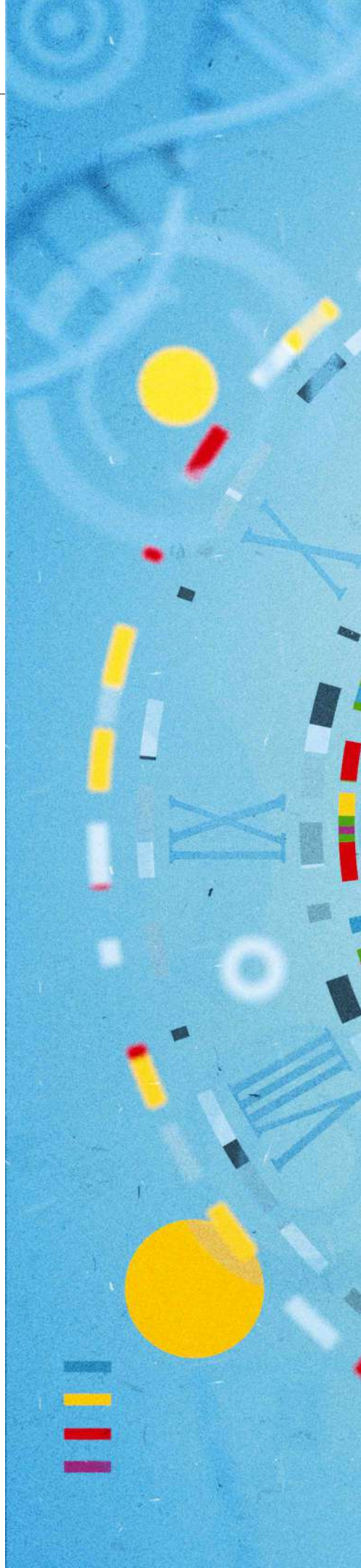
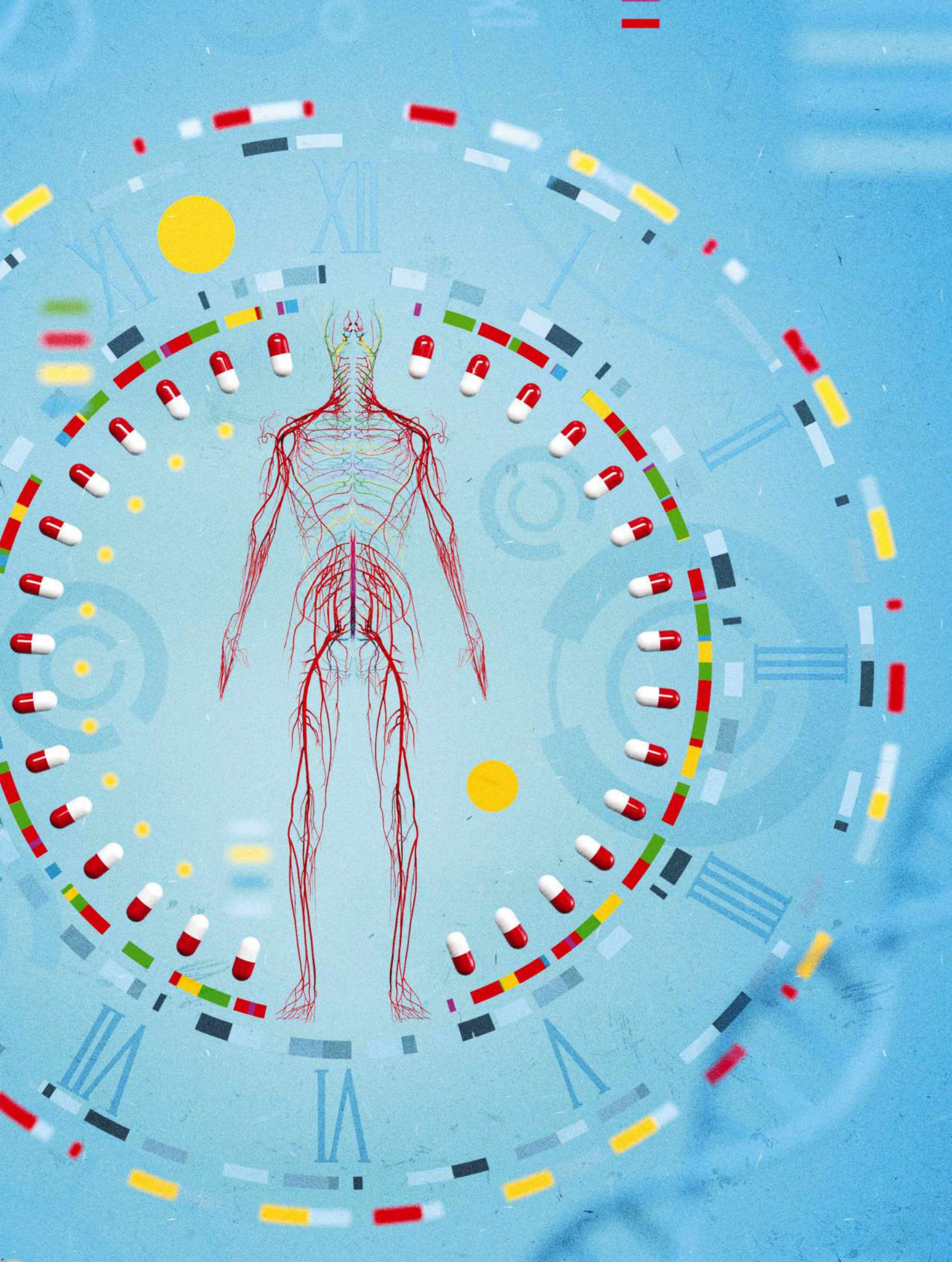


ILLUSTRATION: MAGIC TORCH



trials are beginning to assess if their promise holds true in humans. If it does, those who are middle-aged now could become the first generation to benefit from their use. Imagine an 80-year-old with the biology and 'get up and go' of someone 30 years younger. How joyful not to have to act your age!

LIVE BETTER FOR LONGER

In the last couple of decades, the science of anti-ageing has moved from science-fiction into academically rigorous, evidence-based, peer-reviewed science. It's not about achieving immortality, having your brain cryogenically preserved or any of the other outlandish propositions that have been mooted. "There are a lot of people out there who sell you snake oil and tell you that you'll live forever, and then when you die, nobody sues them," says Dr Nir Barzilai, director of the Institute for Ageing at the Albert Einstein College of Medicine in New York. Instead, it's about improving what scientists call the 'healthspan', or the number of years that people can live well without disease. Extending the lifespan could be a fortuitous side effect, as could the ramifications for the economy.

Currently, 80 per cent of the world's adults aged 65 or over have at least one chronic illness, while 68 per cent have two or more. The human suffering is huge, and in the next 30 years, the number of over-65-year-olds is projected to double to 1.5 billion. This will be costly. "If we had a drug that adds even one or two healthy years onto the lifespan, it would have trillions of dollars of effect on the world economy, because people would be productive for longer and they wouldn't have all these morbidities that cost our healthcare systems so much," says Jim Mellon, chairman of the longevity company Juvenescence.

It's no coincidence that age is the biggest risk factor for illnesses such as cancer, cardiovascular disease and neurodegeneration. The ageing process involves a whole raft of biological changes that drives their development. Scientists call these changes 'hallmarks' and around nine have been identified (see 'The Hallmarks Of Ageing', p57), including the accumulation of genetic mutations, the unravelling of chromosomes and the impaired ability of tiny cellular power packs, called mitochondria, to function. According to the theory, if you can correct these problems, you won't just slow down ageing, you'll also prevent or defer many of the diseases that are associated with old age.

In December 2021, researchers from the University of the Chinese Academy of Sciences in Shanghai revealed that a natural compound found in grape seeds could prolong the lifespan of old mice by 9 per cent, and make them physically fitter too. The compound, called procyanidin C1, works by targeting another of the hallmarks of ageing: the build-up of tired, worn-out cells that are described as 'senescent.'

GETTY IMAGES X2

In our younger years, the immune system clears senescent cells from the body before they can cause a problem, but as we age and our immune system falters, the cells get to hang around, secreting inflammatory molecules that injure the surrounding tissue. "It's like a fire that spreads," says Ming Xu, who studies senescence at the University of Connecticut's Centre on Ageing. "It's a very small population of cells, but they have a very large and very damaging effect." Drugs that seek out and kill these senescent cells, known as senolytics, are among the most promising anti-ageing therapies.

Xu and colleagues have shown that when small numbers of senescent cells are transplanted into mice, it ages them. Then when the same mice are treated, not with procyanidin C1, but with a cocktail of two different senolytic drugs, the rogue cells are destroyed and the mice become more robust. They develop stronger muscles, become more active and live longer. The same results are seen in mice that have aged naturally.

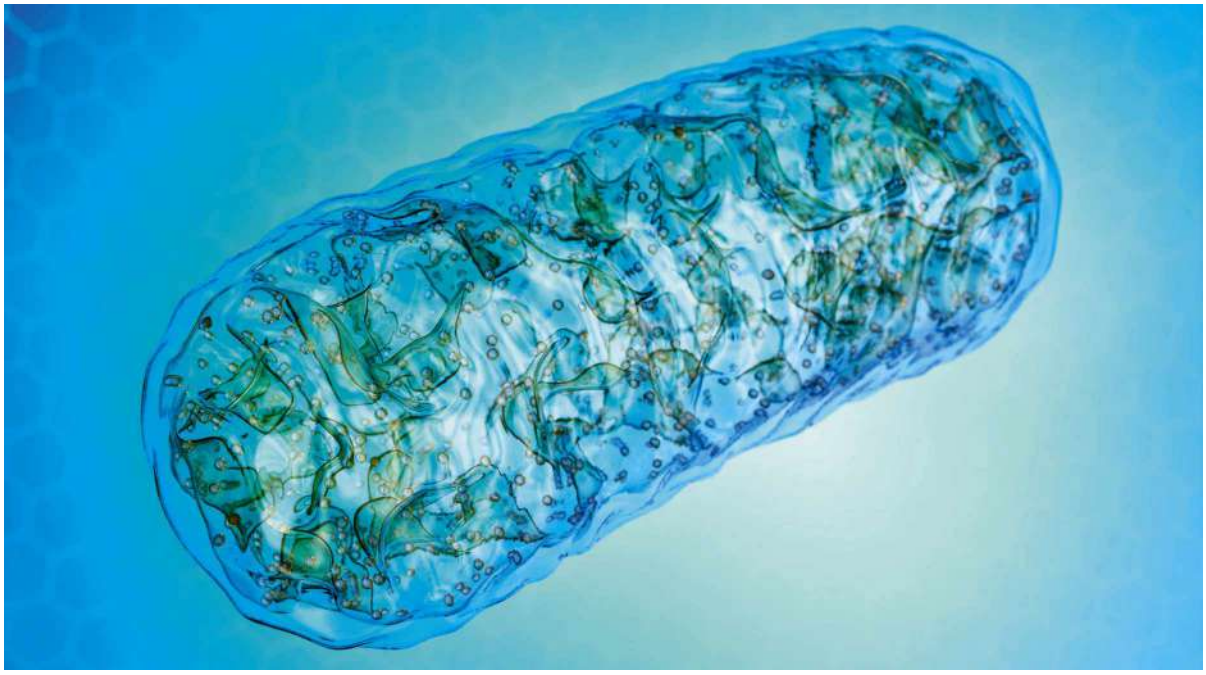
It's all the more impressive because the mice received the drugs very late in life, when they were already two years old. "It's the equivalent of a person beginning treatment when they are 70 or 80, and then having their healthy lifespan extended by five to six years," says Xu. Also encouraging is the fact that these drugs are already known to be safe for human use. Quercitin, which is a plant pigment found in many fruits and vegetables, is sold as a dietary supplement, while dasatinib is approved for use as a blood cancer drug.

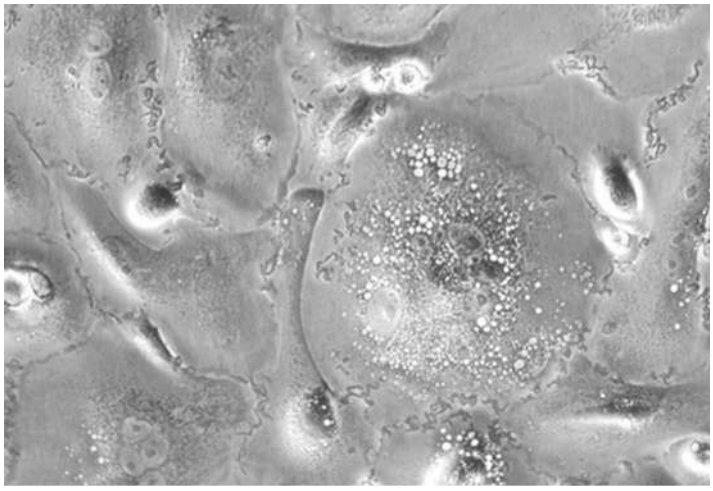
"DRUGS THAT SEEK OUT AND KILL THESE SENESCENT CELLS, KNOWN AS SENOLYTICS, ARE AMONG THE MOST PROMISING ANTI-AGEING THERAPIES"

Further animal studies have shown that senolytic drugs can delay, prevent or ease more than 40 diseases, including cancers and various disorders of the heart, liver, kidney, lung, eye and brain. Preliminary studies in humans show that they reduce the number of senescent cells, curb inflammation and alleviate frailty, and now dozens of clinical trials are underway to assess

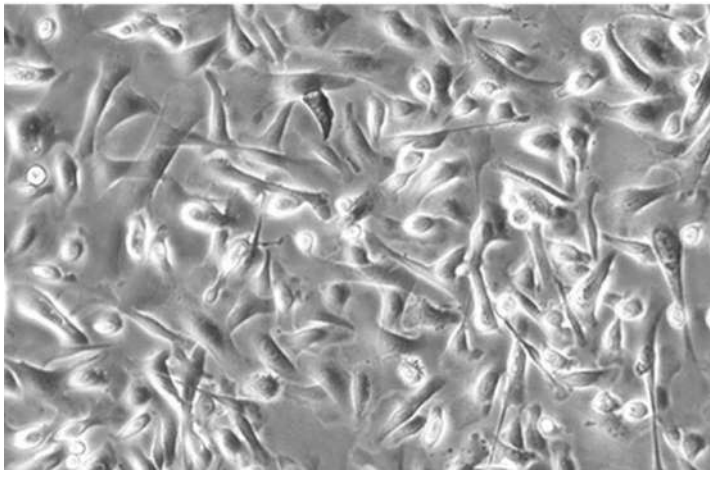
ABOVE LEFT Staving off physical and mental decline is vital if we're expected to live longer

RIGHT The ability of our mitochondria, essentially the batteries of our cells, declines as we age





The different proliferations of keratinocytes, a type of skin cell, in an old mouse (top) and a young mouse (boffom)



BIRGIT RITSCHKA/RESEARCH INSTITUTE OF MOLECULAR PATHOLOGY VIENNA, ILLUSTRATION: ACUTE GRAPHICS

"AS PART OF THE DOG AGING PROJECT IN THE US, 500 CANINES ARE HELPING TO ASSESS THE WORTH OF ANOTHER PUTATIVE ANTI-AGEING TREATMENT, CALLED RAPAMYCIN"

their impact on various conditions, including diabetes, arthritis and Alzheimer's disease.

All of these trials will yield vital information, but if a senolytic or any other drug is ever to be used as a genuine anti-ageing therapy, it'll need to pass muster in the human equivalent of Xu's mouse study. As well as testing these drugs in people who already have disease – as is happening in the current clinical trials – they also need to be rigorously tested in healthy people who are ageing naturally.

SPEEDING UP A SLOW PROCESS

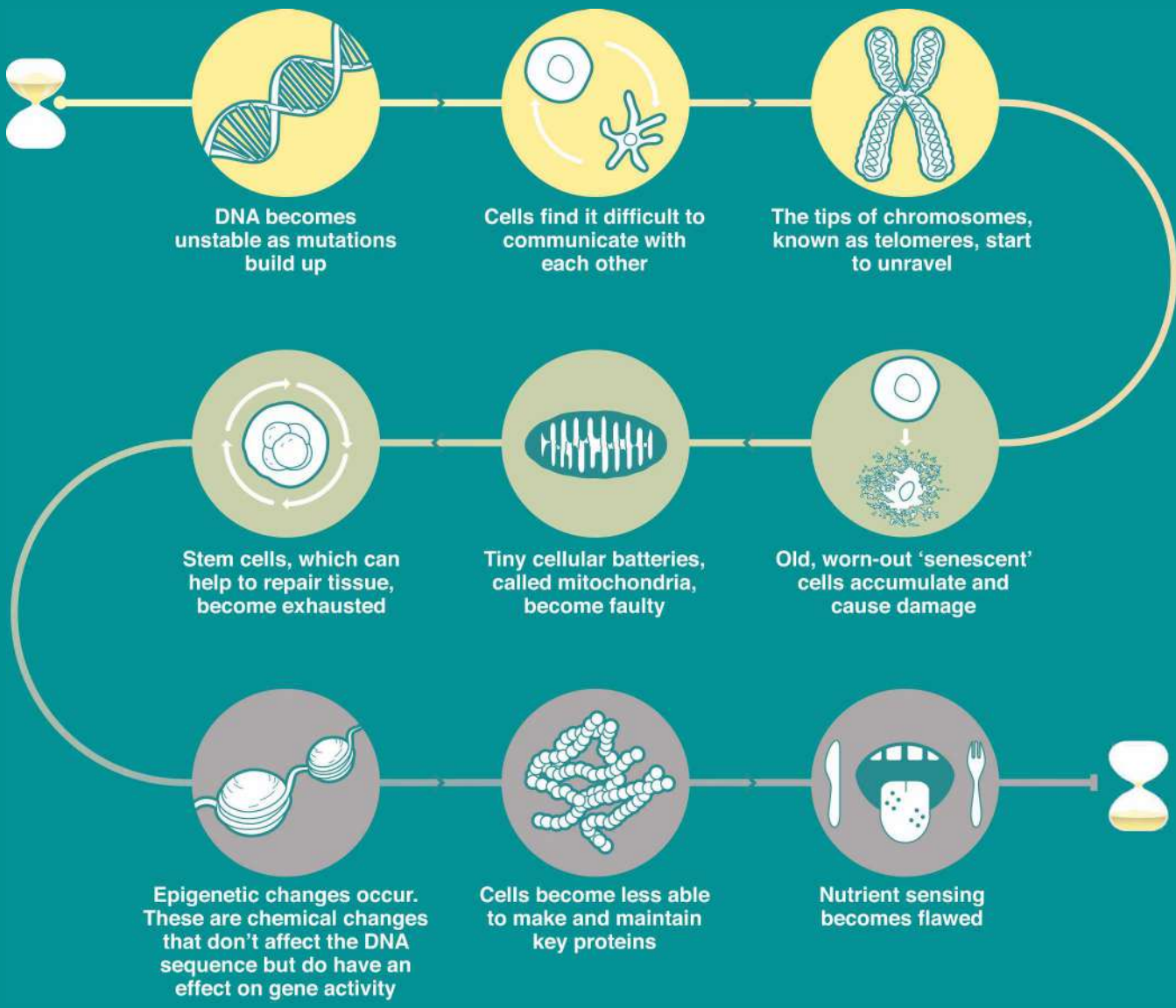
It's a conceptual no-brainer and should be straightforward, save for a couple of problems. The first is that humans take decades to age, a predicament that makes the requisite trials both lengthy and expensive. One potential solution to this problem, currently under investigation, is to use molecular proxies or 'biomarkers' of the ageing process. These are subtle changes, such as the addition of certain chemical groups to DNA, that occur across smaller time frames and are thought to be indicative of the broader ageing picture.

Another option is to turn to man's best friend. Dogs age around seven times faster than humans, and experience many of the same age-related diseases and declines. They also share our homes and many of the same environmental influences that contribute to ageing. In short, they're an excellent model of the ageing process, and are willing to help out in exchange for treats and belly rubs.

As part of the Dog Aging Project in the US, 500 canines are helping to assess the worth of another putative anti-ageing treatment, called rapamycin. Rapamycin also targets senescent cells, as well as several of the other hallmarks of ageing. Relatively large doses are given to transplant patients to help prevent organ rejection, but in small doses it's been shown to prolong life in yeast, worms, flies and mice. The dogs will be followed for up to a decade and if rapamycin's promise holds true, those who receive the therapy could have their lives extended by up to four human years (or 28 dog years).

THE HALLMARKS OF AGEING

Scientists have started to identify key features or 'hallmarks' of the ageing process. Therapies that target these hallmarks have the potential to slow ageing. They could also prevent, ease or delay illnesses, such as cancer, diabetes and heart disease. As a result, the hope is not just that we will live longer, but that we will lead healthier lives too


DNA becomes unstable as mutations build up
Cells find it difficult to communicate with each other
The tips of chromosomes, known as telomeres, start to unravel
Old, worn-out 'senescent' cells accumulate and cause damage
Tiny cellular batteries, called mitochondria, become faulty
Stem cells, which can help to repair tissue, become exhausted
Nutrient sensing becomes flawed
Cells become less able to make and maintain key proteins
Epigenetic changes occur. These are chemical changes that don't affect the DNA sequence but do have an effect on gene activity

Quercitin is a plant flavonol with a bitter taste, found in dietary supplements, beverages and food. It's known as a 'senolytic' because it kills the senescent cells that contribute to ageing. Senolytic drugs have been shown to extend life and stave off disease in animals. Human clinical trials are underway.

Rapamycin is an immunosuppressant drug. It targets several of the hallmarks of ageing (described above), including impaired nutrient sensing, dysfunctional mitochondria and declining stem cell function. In one key study, three months of rapamycin treatment improved the healthy lifespan of middle-aged mice by 60 per cent.

Metformin is used to treat type 2 diabetes. It's a particularly exciting anti-ageing drug because it targets all of the nine known hallmarks of ageing. A landmark clinical trial called Targeting Aging With Metformin (TAME) is currently underway in the US and assessing if the drug can slow ageing and defer age-related disease.

"WE DON'T WANT TO CALL AGEING A DISEASE. THE PEOPLE WE WANT TO HELP DON'T WANT US TO CALL THEM SICK, BUT AGEING DOES NEED TO BE OFFICIALLY RECOGNISED AS AN 'INDICATION' THAT IS TREATABLE"

The second problem with arranging the requisite human studies is less practical and more attitudinal. According to the current medical paradigm, ageing is not something that needs to be treated. Along with hangovers and nuisance phone calls, ageing is viewed as a grim inevitability of life. If the US Food and Drug Administration (FDA) and other medical regulators are ever to approve a drug for ageing, they would first need to recognise that ageing is a preventable condition that can be targeted therapeutically. "We don't want to call ageing a disease," says Barzilai. "The people we want to help don't want us to call them sick, but ageing does need to be officially recognised as an 'indication' that is treatable."

So Barzilai has found a way around the conundrum. His focus is on another potential anti-ageing drug, called metformin. Metformin is a cheap and successful medicine. Every day, millions of people take it to control their type 2 diabetes, but in 2016, Barzilai suggested it could be used to slow ageing. Key to his argument is a 2014 UK clinical trial involving over 150,000 people, which revealed that diabetics taking metformin live longer than non-diabetics who don't, and a growing number of separate studies that demonstrate metformin's ability to prevent specific age-related disorders. Taken together, these studies hint that metformin may be able to improve the healthspan, but they don't quite nail it. What's needed is a clinical trial that ties all these loose ends together in a single, well-designed study. Enter, the 'Targeting Aging with Metformin' (TAME) trial.

Barzilai and colleagues are recruiting 3,000 adults, aged 65 to 80, who don't have diabetes, to receive either metformin or a placebo over a four-year period. During this time, the team will monitor age-related biomarkers and the time it takes for each of the patients to develop a major age-related disease, such as dementia or stroke. Instead of looking at the ability of metformin to delay a single age-related disease, as the other trials have done, this study will assess the drug's capacity to delay the onset of age-related disease in general. It will show if metformin can increase the healthspan.

If the trial succeeds, its effects could be far-reaching. TAME has the power to prove that ageing really is something that can be targeted and treated with drugs. This, in itself, will be a

SHUTTERSTOCK, ALAMY, ALBERT EINSTEIN COLLEGE OF MEDICINE

ABOVE Metformin is a cheap diabetes drug that has potential as an anti-ageing treatment

ABOVE LEFT Dogs age in similar ways to humans but considerably faster, so are useful proxies

RIGHT Dr Nir Barzilai and his team are investigating ways of increasing human healthspans

major paradigm shift. "We hope it will inspire the FDA to make ageing an indication and provide a template for other biotech companies to do similar studies," says Barzilai. While other scientists pursue different anti-ageing strategies, such as gene therapy or tissue transplants, taking tablets is so much simpler. Metformin could become the first authorised anti-ageing drug with the ability to not just prolong life, but to prolong a healthy life. Then after metformin, other anti-ageing drugs could follow. Instead of treating each age-related medical condition separately, as currently happens, it's possible to imagine a future where these conditions are 'treated' together, by targeting multiple hallmarks of ageing.

Just as statins are doled out today to lower cholesterol, and prevent strokes and heart disease, so too anti-ageing medicines or 'gerotherapeutics' could be prescribed to prevent the diseases of old age. Based on the results of a blood test, which could indicate how fast you're ageing and which diseases you're prone to, a clinician might prescribe one or more anti-ageing drugs. Metformin, rapamycin, quercitin, dasatinib and other as-yet-unidentified anti-ageing drugs could all be part of the picture. It would mark a shift away from the prevailing medical model, where diseases are treated reactively after symptoms have occurred and suffering has set in, to a preventative model of care, where patients are monitored proactively and future diseases are averted.

With a handful of promising anti-ageing drugs already in existence, ageing has never looked so 'treatable', and yet, there's just one final problem. Clinical trials don't come cheap, so the question is, who pays?

Government funding agencies seemingly aren't keen to invest in the anti-ageing area. Regulators don't tend to fund studies of drugs that are already on the market, and the pharmaceutical industry won't cough up for trials of drugs that are generic, cheap or off-patent, with no profit margin. The 30 or so bona fide anti-ageing companies that exist are more interested in developing their own proprietary therapies than readily accessible drugs such as metformin or quercitin. Until additional funding can be found, this means that safe, affordable drugs with the potential to slow ageing and extend the healthspan are not being properly explored. Meanwhile, the people who need them most are growing old waiting. **SF**

by **DR HELEN PILCHER** *(@HelenPilcher1)*
Helen is a science writer who isn't getting any younger. Her latest book is Small Inventions That Made A Big Difference *(£14.99, Welbeck).*

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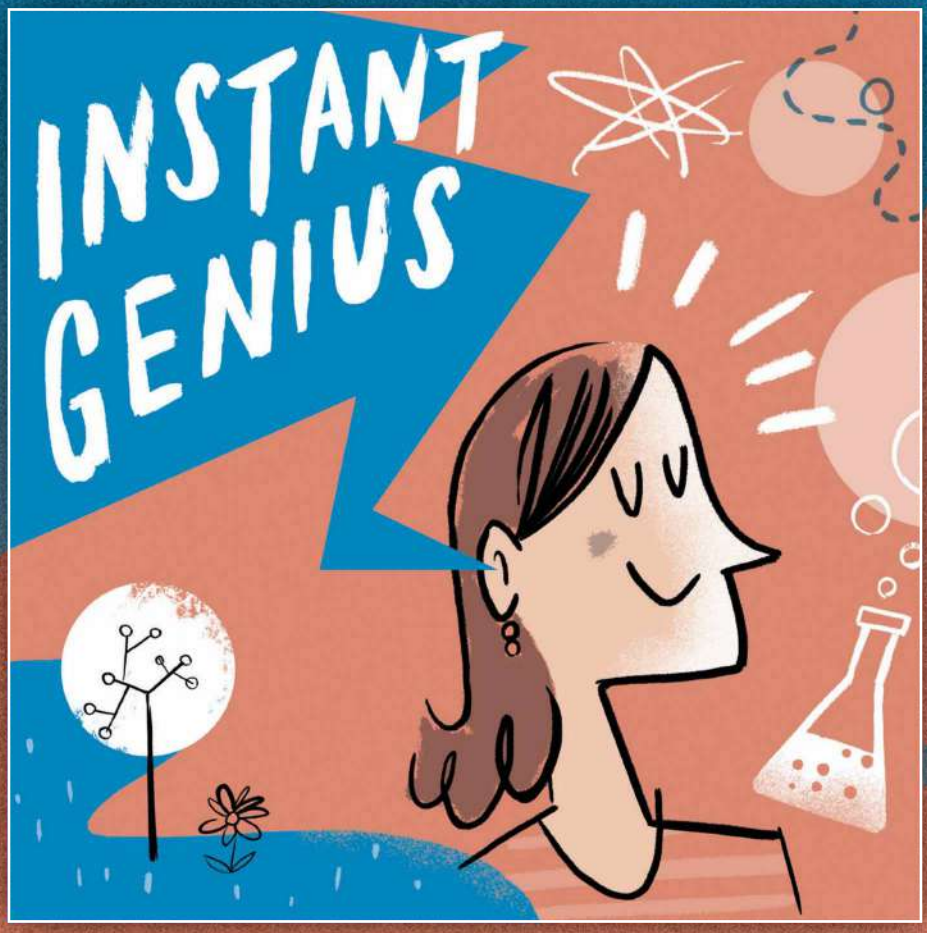

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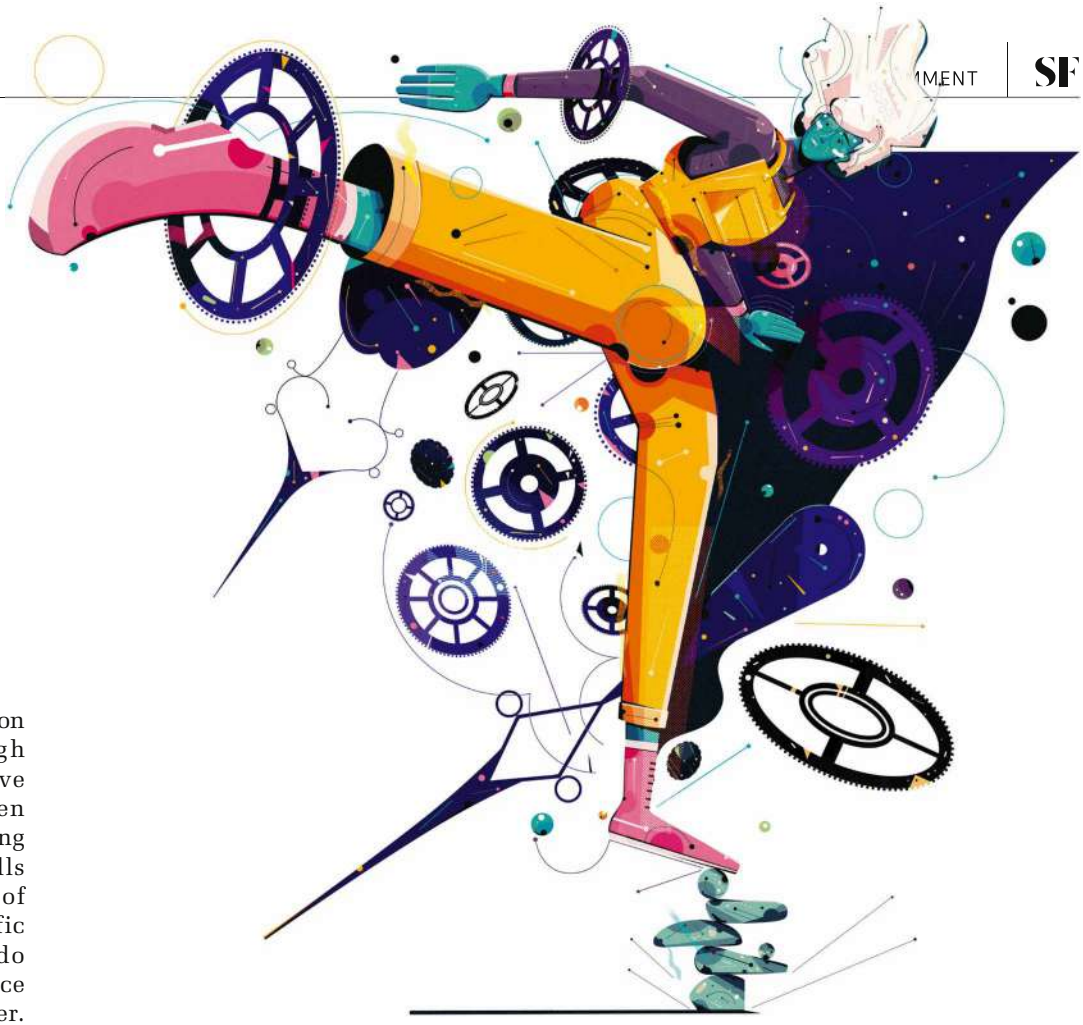

COMMENT

A BALANCING ACT

Unleash your inner five-year-old and practise standing on one leg, to keep your brain working hard

A common New Year's resolution is to get fitter. Although people determinedly heave weights or run, they often forget the importance of working on their balance. Worldwide, falls are the most common cause of accidental death after road traffic accidents, and unless you do something about it, your balance will deteriorate as you get older. And having good balance is a powerful predictor of how long and how healthily you will live.

A good test of your balance is to see how long you can stand on one leg, first with your eyes open and then closed. Take your shoes off, put your hands on your hips and stand on one leg. See how long you last. The test is over as soon as you shift your planted foot or put your raised foot down on the ground. Best of three. Then repeat, with your eyes closed. You will be dismayed by how quickly you start to fall over. Here are the targets that different age groups should be able to manage:

Under 40: 45 seconds with eyes open, 15 seconds with eyes closed.
Aged 40-49: 42 seconds open, 13 seconds closed.
Aged 50-59: 41 seconds open, 8 seconds closed.
Aged 60-69: 32 seconds open, 4 seconds closed.
Aged 70-79: 22 seconds open, 3 seconds closed.

"Although people heave weights or run, they often forget the importance of working on their balance"

How much does it matter? In a study published in the *BMJ* in 2014, researchers tested 2,760 men and women who, at that time of testing, were all 53 years old. They measured grip strength, how quickly they could stand upright from sitting and how long they could stand on one leg with their eyes closed.

When the researchers returned 13 years later, they found that the tests had all, independently, predicted the chance that someone would die over that period, but the one-legged standing test was the best. Those individuals who lasted less than two seconds were three times more likely to have died than those who held it for 10 seconds or more.

Why is this balance test so important? It's because it is so taxing. Your brain normally uses three different types of information to keep you upright: your eyes, your vestibular system (a sort of spirit level you have in your inner ear), and proprioceptors in your limbs that send signals to your brain, telling it what is going on. When you remove your eyesight, the brain has to work much harder to keep you steady.

The good news is you can improve your balance with activities such as yoga or tai chi. I practise balancing on one leg while brushing my teeth. You can find other suggestions by searching online for 'NHS balance exercises'. It really is worth taking the time to work at it. **SF**

MICHAEL MOSLEY

Michael is a writer and broadcaster, who presents *Trust Me, I'm A Doctor*. His latest book is *COVID-19: Everything You Need To Know About Coronavirus And The Race For The Vaccine* (£6.99, Short Books).

BBC TWO

PORTRAIT: KATE COPELAND ILLUSTRATION: JOE WALDRON

COMMENT

NOT MY FIRST METAVERSE

Facebook CEO Mark Zuckerberg might be getting excited about the metaverse, but the idea is nothing new

ALEKS KROTOSKI

Aleks is a social psychologist, broadcaster and journalist. She presents *The Digital Human*.

BBC RADIO 4 92–95FM & 198LW

Last month, I spent my valuable column inches predicting what we would be obsessed with over the next 12 months. Already I'm proving to be a terrible fortune teller, because the one thing that I should have known was coming was so obviously on the cards that I ignored all the signs. How could I not foresee the metaverse?

You may have heard this word recently, perhaps for the first time. The big tech companies are propelling it forward with vigorous press releases and starry-eyed hot takes bordering on the messianic. Briefly, a metaverse is a virtual reality that exists in a layer above the physical, and yet reflects and replicates the things that we need for society to function: economies, hierarchies, judicial systems, and so on. In other words, it's what we do now, only online with avatars, VR headsets and augmented reality.

Perhaps the reason I didn't see it coming is very simple. This isn't my first metaverse. It's not even my third. A metaverse comes around every time there's a new way to interact with technology. This is not a problem *per se*. It simply demonstrates that we have short-term memory issues.

Each iteration of the 'metaverse' does get closer to the original (dystopian) definition first coined by author Neal Stephenson in his magnificent 1992 novel *Snow Crash*. The people who populated 1990s online community LambdaMOO pushed the boundaries of how to deal with unacceptable social behaviour in its anarchic text-based playground; the architects who landscaped ActiveWorlds' 3D reality found the limits of server space and acceptable behaviour; the capitalists who descended on virtual world *Second Life* in the 2000s forced a reckoning with tax regimes and, again, unacceptable behaviour. People will always misbehave! Every metaverse has come to this 'problem' with wide eyes and optimism, thinking it has solved human behaviour, but we have a way of unravelling things.

"Big tech companies are propelling the metaverse forward with starry-eyed hot takes"

But none of these examples I've listed are metaverses in the true sense because they're all owned by single companies who fiercely guard their intellectual property, creating walled gardens of the future. They are also not untethered from physical space, as they have to operate within the bounds of the jurisdictions their customers physically reside in. The metaverses Facebook and Microsoft are promising will do the same. What's more interesting is what edges they will find themselves pushing up against; the things that we will reject because we don't realise what is important to us until it's not there. A VR headset and a handshake with an avatar operated by a single mother from Illinois inside a 3D representation of a city street imagined by an anarchist from Angola is neat and all, but as we have seen before, that's only one way the tech will be used. The rest may not be as acceptable.

Metaverses are exciting. They let us think we can create in remarkable, unexpected ways. But they are technological sandboxes with boundaries defined by the limitations of what we use to access them. As things get even more meta, get excited about the possibilities. Just don't put your faith in the things being promised today. The metaverse won't be here anytime soon. SF

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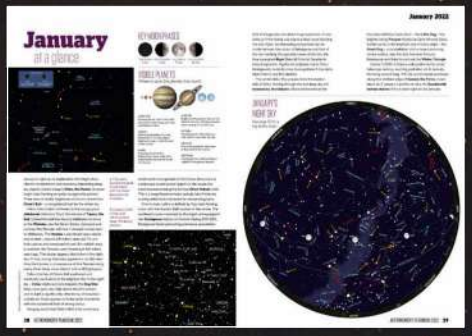

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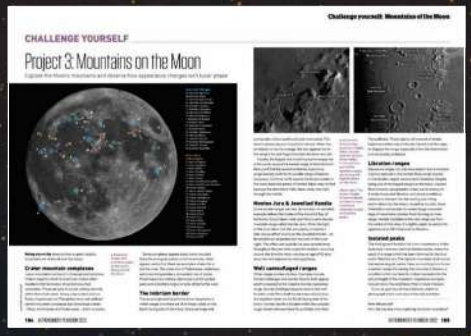

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TERRY HANCOCK

BBC STUDIOS

BBC TWO

These incredible organisms feature in the first episode of Sir David Attenborough's new show, *The Green Planet*, which is available to watch now on BBC iPlayer.

A WINNING FORMULA

Beneath the rainforests of South America lives a fungi that consumes 50,000 leaves a day without ever coming to the surface. It relies on ants to bring it food in exchange for nutrients. This unlikely partnership starred in Sir David A enborough's new wildlife series *The Green Planet*. Evolutionary biologist **Dr Pepijn Kooij** speaks to **Amy Barrett** about this special relationship...

THE LEAF-CUTTER ANTS RELY ON THEIR FUNGUS FOR FOOD. WHY DON'T THEY JUST CUT OUT THE MIDDLEMAN AND EAT THE LEAVES THEMSELVES?

Digesting plant material is a difficult process, even for us humans. It's a hard thing to do.

Think about herbivores, carnivores and omnivores, and just look at, for example, the lengths of their intestines. If you take a tiger – a carnivore – the length of its intestines is about six metres. But if you look at a cow – the perfect example of a herbivore – the intestine is about 24 metres long, and cows also have multiple stomachs. It's a long process to digest plant material, and you need lots of different bacteria to help you do it.

Plants have this defence mechanism: an enormous cell wall around their cells to protect them from being eaten. It takes a lot of energy to get to the parts in the plants that we actually need – the nitrogen and proteins. But there are specialised organisms, such as bacteria [in a cow's stomach], that are designed to do that kind of work. For the ants, they want those proteins, but it's very hard for the insects to actually extract them. So they have their fungus help penetrate the cell, then the ants feed on the fungus.

BUT DOESN'T THE FUNGUS NEED THE PROTEIN? WHY WOULD IT SHARE?

Well, the fungus takes some of the proteins, but it has developed this relationship with the leaf-cutter ants. The fungus grows specialised organs, which we call gongylidia. Inside the gongylidia are fats and proteins, which are nutritious for the ants. The ants eat these gongylidia.

But the fungus also benefits from this relationship. Usually, fungi need to release enzymes that let them break down plants to absorb the nutrients. With the leaf-cutter ant partnership, the fungus fills its gongylidia with enzymes. The ants eat these enzymes when they feed on the gongylidia, but they ➔

cannot digest them, so they are still active when the ants poo them out. The ants will bring new plant material into the nest, place it on the fungus and then poo on top. This gets the fungal enzymes exactly where they need to be to break down the plants. The fungus is using the ants like trucks, to transport the enzymes from one part of the fungus to the place where the new plant material is located.

If you watch the first episode of *The Green Planet*, you'll notice the fungus looks like a big ball. This ball *is* the fungus, made up of what's called the mycelium.

These organisms are often called fungus-growing ants, but I think ant-growing fungi could be a better term.

ANT-GROWING FUNGI?

So, 'fungus-growing ants' is term that the Royal Botanic Gardens, Kew, first used in the late 19th Century for these ants that farm fungi as their main food source. I've been trying to change the view more into ant-growing fungi.

This is a mutualism, and a mutualism has a benefit for both [parties]. To say that the ants are growing the fungus is a bit one-sided. Of course, they bring in the leaves and they grow the fungus on there. But the fungus is also directing and giving assignments to the ants somehow, using chemical communication. So you could also see it as ant-growing fungi.

"The fungus is using the ants like trucks, to transport the enzymes from one part of the fungus to the place where the new plant material is located"

It's as if the fungus is using the ants, sort of like cattle. Seeing the system that way brings up lots of different questions. Our research is trying to untangle this whole system to see how it works. Because in the end, it's a mutualism and you could even see that as one big organism.

In the same way we humans have lots of bacteria in our guts, but we still see ourselves as one system. We wouldn't say we are a human and bacteria. So in that sense, it's not ants that grow fungus, it's ants and fungus together.

YOU SAID THE BALL WAS MYCELIUM. WHAT IS THAT?

You might've seen fungi in the form of a mushroom, but this is only a small percentage of the actual organism.

BBC STUDIOS, GETTY IMAGES

In a forest in England, for example, you might see mushrooms, but there will be metres and kilometres of mycelium underneath the soil that you don't see.

This mycelium is much more important [than the mushroom] for the fungus. In fact, the mycelium *is* the actual fungus. The mushroom is only a sexual reproduction tool.

The best comparison you might make is something like an apple tree, with the apple that contains its seeds, or a plant's flower and its pollen. So, the mushroom is then analogous to the flower and it creates the spores, which are like the pollen.

It's only that small part of the fungus, the mushroom, that you actually see, which is the most pretty part, of course. Though mycelium can look very pretty – I can tell you that with certainty. But in general, you can't see the mycelium because it's very thin, thread-like structures in the soil.

It's the mycelium that extracts all the nutrients. It does all the hard work. And then bubbles together to form the mushroom.

ABOVE Leaf-cutter ants share their colonies with a fungus, which they cultivate with the leaves they retrieve

ABOVE LEFT Sir David Attenborough takes you into the surprising world of plants, trees and fungi in *The Green Planet*

WHY DON'T THE ANTS JUST EAT THE MUSHROOM?

Normally, this particular fungus doesn't need to grow mushrooms for sexual reproduction, because the ants help spread the fungus.

Every generation of ants begins with a new queen, and the new queens will take a piece of the fungus into a special cavity in their mouth that they take away when they fly out to mate and start a new colony.

This is a process we call 'vertical transmission'. It makes sure that there is a continuation of this particular strain of fungus without any genetic mixing.

Producing a mushroom requires a lot of energy that is wasted on something that's unnecessary. Also, the ants can't eat the mushrooms.

When I studied these [fungi] species in Copenhagen, we kept them in climate-controlled rooms. Sometimes the climate chambers had problems – a sudden decrease in temperature, or the humidifier might not be working very well – and we would get mushrooms. The ants would attack those mushrooms. They would cut away at the lamellae [gills] on the underside of the mushroom cap, where the spores are formed, and try to get rid of the mushrooms.

Now, in the campus where I am in Brazil, every now and then we see mushrooms coming up. It's very, very strange to see. One of the PhD students that I started working with at São Paolo State University, Rodolfo Bizarria Jr, started counting how many times we saw this. Then we went back through the literature to find all the occurrences [of mushrooms appearing]. There aren't many, going back all ➲

RIGHT Dr Pepijn Kooij has been studying how leaf-cu er ants and fungi have formed a mutualism

the way to the 19th Century. But we can see an increase. We tried to determine whether there was a correlation with the temperature, the humidity and the precipitation, and there does seem to be a link.

COULD CLIMATE CHANGE AFFECT THESE SPECIES?

We don't know yet. We just know there is an increase in mushrooms, and normally this is not profitable for the system. We would have to look into if this is going to be really detrimental for the colony.

WHERE IS THIS FUNGI-ANT SYSTEM FOUND?

Only in the Americas. So, you can find fungus-growing ants in the southern parts of South America, around Argentina and Chile, all the way up to the southern parts of the United States – Florida, Arizona, Texas. Even on the Caribbean islands you can find some of these species.

WHY DID THIS RELATIONSHIP BEGIN?

That's the big question. We don't know. There are several different theories, and the most common is that it might have originated from ants that started collecting plant material as food. The ants deposited the material inside the nest chambers and then a fungus started growing on it, and somehow they realised, "Hey, this is nice!" Kind of like how we discovered how to make beer, for example, or other alcoholic products, because fungi started growing on our rotting food and eventually we realised, "Oh, but that's actually very nice."

But the exact connection, we don't know for sure. We know more about the ants because people have studied them more. So we're much closer to understanding the ant ancestors than when we started doing this.

We don't know what the closest ancestors of these fungi are. A key part of my research is trying to find that out and trying to understand why these ants chose this fungus and not another one. What is so good about these fungi and what is the origin of the fungus that is related to it, those that aren't growing with ants? Once we know that we might be able to compare the genomics and the ecology. With that, at least, we can make some inference of how this all started.

BUT THIS ISN'T JUST A RELATIONSHIP BETWEEN ANTS AND FUNGI. HOW HAVE THE PLANTS ADAPTED TO PROTECT THEMSELVES FROM BEING EATEN?

Plants have their own defences, and they're not necessarily particular to these ants, but a general protection against herbivores. One way they do this is by producing toxins, which we call phenolic compounds. Tannins are an example for that. So, if you have a nice glass of wine, the tannins in your mouth – the drying, bitter taste – are the defence mechanism of plants.

That acidity is very good at fending off any fungi, any bacteria – and with that any

BRG KEW, BBC STUDIOS

“We don’t know what the closest ancestors of these fungi are. A key part of my research is trying to find that out and trying to understand why these ants choose this fungus and not another one”

herbivores, because it would disrupt their microbiome.

However, another defence is other fungi. Inside plant leaves you’ll find what we call endophytes. These are fungi that form, in most cases, a mutualism with the plant, to protect it against herbivores. They would not like to have other fungi in their food!

Studies with leaf-cutting ants showed that when presented with leaves infected with endophytes, the ants would always go for the leaves that had the least. Because otherwise you might get competition between their fungus and the fungi in the leaf.

HOW DO THEY KNOW?

Good question. We think that the ants can smell it. They don’t have noses, of course, but with their antennae they’re able to pick up odours, chemicals and volatiles released by the plants or coming from the fungus. That’s another way the fungus communicates with its ant colony. The ants might give something to the fungus and the fungus can give off a signal that says, “I don’t like this one.”

Studies by a group in Germany gave the ants little pieces of leaves treated with fungicides. After 24 hours, the ants stopped bringing those to the fungus. It’s not that the ants that recognised the fungicide, but they recognised something was wrong because the fungus was not liking it. There’s a really tight interaction between the fungus and the ants. **SF**

LEFT Leaf-cutter ants have a mutually beneficial arrangement with fungi, which does the hard work of digesting leaves for them

DR PEPIJN KOOIJ

Pepijn is a researcher in the Laboratory of Fungal Ecology and Systematics at the Universidade Estadual Paulista in Rio Claro, Brazil. Kooij is currently looking at the effects of climate change on fungus-growing ants. He previously worked at the Royal Botanic Gardens, Kew, with a team of fungal specialists called mycologists.

GETTY IMAGES

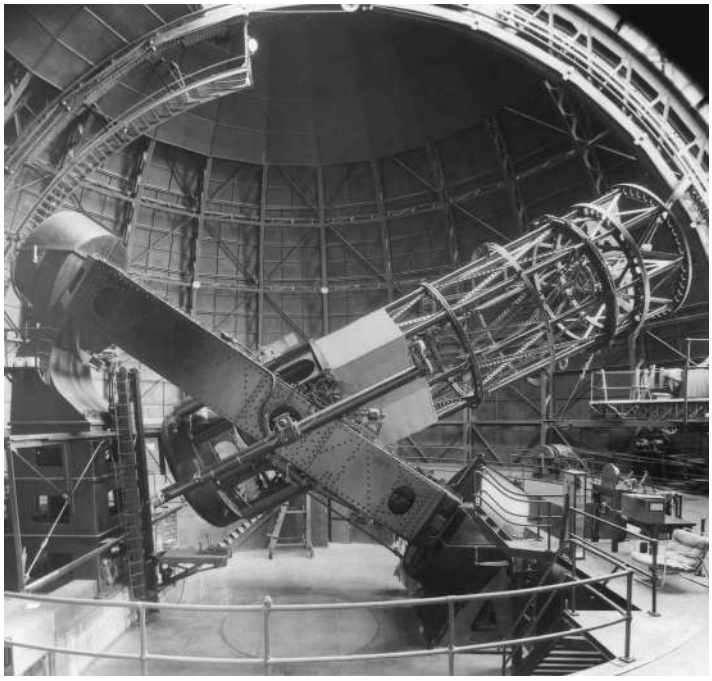
THE LIGHT FANTASTIC

As new telescopes around the world power up, they could answer an ancient mystery: what's powering the most energetic explosions in the Universe?

BY MARCUS CHOWN

Thirty light-years away, a star explodes. For several months, it shines 10,000 times brighter than the full Moon. It's so bright that, during the day, it looks as if the Sun has been joined by another sun, pumping out a hundredth as much heat and light.

The good news is that you can sleep easy tonight, because this scenario would not happen. Life on Earth is safe from such an event. Superluminous supernovae – up to 100 times as powerful as any stellar explosion previously known – are not only very rare, but appear to detonate in galaxies quite a bit different from our own.



ABOVE Fritz Zwicky (pictured), along with Walter Baade, coined the term 'supernovae' in the 1930s

ABOVE RIGHT Edwin Hubble used the Hooker Telescope to spot galaxies many light-years away, where Zwicky and Baade later observed supernovae

In 1931, Fritz Zwicky and Walter Baade, working at the California Institute of Technology in Pasadena, made an astonishing claim about exploding stars, or 'novae'. Their work built on a discovery made eight years earlier by Edwin Hubble, who had used what was then the biggest telescope in the world (the 2.5m Hooker Telescope on Mount Wilson, which overlooks Caltech) to show that the mysterious spiral nebulae were in fact galaxies – great islands of stars separate from the Milky Way and millions of light-years away.

Zwicky and Baade noticed that sometimes such galaxies hosted stellar explosions, capable of outshining 100 billion normal stars. Knowing that such explosions were enormously further away than ones in our Galaxy, the two astronomers concluded that they belonged to a new class they called 'supernovae', around 10 million times more luminous than standard novae.

TWINKLE, TWINKLE, DYING STAR

The latest leap in luminosity is not as big as a factor of 10 million, but it is still impressive. A superluminous supernovae is about 10 times as luminous as a Type Ia supernova, which is powered by a star-shattering explosion of a white dwarf – a compact stellar remnant about the size of Earth – that has been swamped by matter from a companion star. And it's about 100 times as powerful as a Type II supernova, the other main type of supernova, which is powered by the implosion of the core of a massive star at the end of its life.

The first superluminous supernova was discovered in 2005 and they were widely recognised as a distinct class of stellar explosion in 2011, principally by the work of Prof Robert Quimby of San Diego State University.

Their existence has come as a big shock to the astronomical community. "We thought we'd discovered all classes of exploding stars," says Dr Matt Nicholl of the University of Birmingham. "How in the world did we miss the brightest ones?"

One reason superluminous supernovae went unnoticed until the 21st Century is they're extremely rare, accounting for only about one in every 10,000 supernovae. The other reason is that supernova searches with telescopes tended to concentrate on big galaxies, with astronomers – quite understandably – reasoning that the more stars in a galaxy, the greater the chance of one going supernova.

Nature, however, had other ideas: it put superluminous supernovae into dwarf galaxies. "Only with the advent of robotic telescopes with wide fields of view were dwarf galaxies caught in our net," explains Nicholl. "Once that started happening, we spotted superluminous supernovae. So far about 100 have been found."

What kind of stars are detonating as such cosmic mega explosions? The biggest clue comes from the explosions' spectra – the way in which the light varies with energy, or equivalent frequency. Astronomers can see the spectral fingerprint of heavy elements such as carbon, oxygen and neon, but not of the lightest two elements: hydrogen and helium. To grasp what this means, it's necessary to understand something about the evolution of stars.

A star like the Sun fuses together the cores, or nuclei, of atoms of hydrogen to make helium, with the by-product being

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sunlight. But in stars that are between 8 and 25 times as massive as the Sun, conditions in the core can become dense enough and hot enough to fuse helium into carbon, carbon into oxygen, oxygen into neon, and so on. Potentially, such fusion reactions can proceed all the way up to iron, at which point they cease to generate any more heat (the hot gas of the core, no longer able to stop gravity from crushing it, promptly implodes).

The result is a star with an onion-like structure: the heaviest elements are in the core with each successive layer containing lighter elements, culminating in helium and finally hydrogen in the outer mantle.

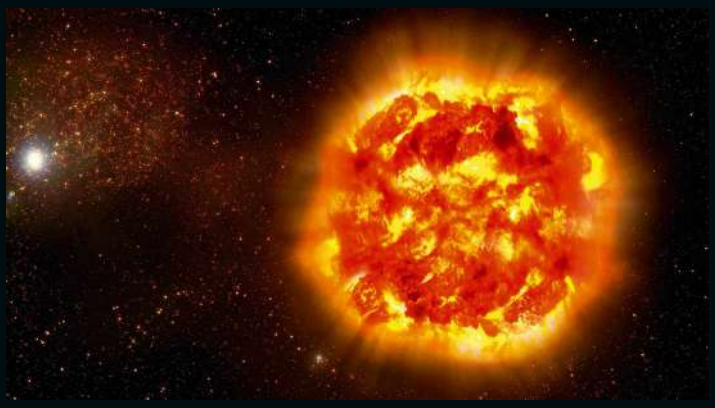
"Somehow the stars that detonate as superluminous supernovae have lost this hydrogen and helium," says Nicholl.

The obvious way for a star to be stripped of its outer mantle of hydrogen and helium is via a stellar wind, similar to but far more powerful than the 1,000,000mph solar wind that blows from the Sun. The problem is that stellar winds are stronger in stars that have a smattering of heavy elements mixed in with their hydrogen and helium mantle. Yet the low-mass galaxies in which the precursors of superluminous supernovae are located are deficient in such elements. This is basically because the galaxies' weak gravities haven't been ➲

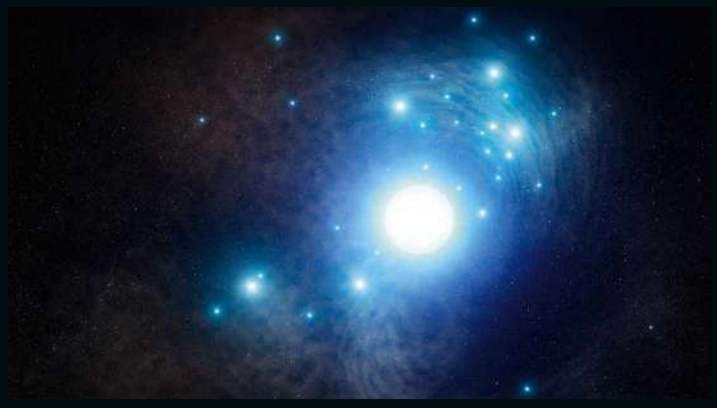
"WE THOUGHT WE'D SPOTTED ALL CLASSES OF EXPLODING STARS. HOW DID WE MISS THE BRIGHTEST ONES?"

SUPERNOVAE ON SHOW

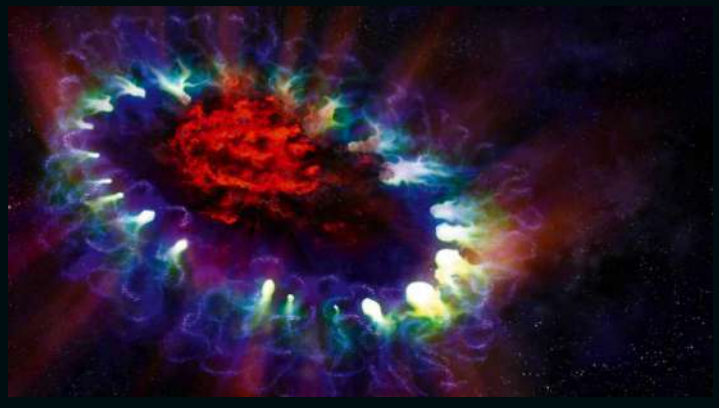
SUPERLUMINOUS
Only around 100 of these supernovae have been identified so far. Astronomers are trying to establish what exactly powers them.



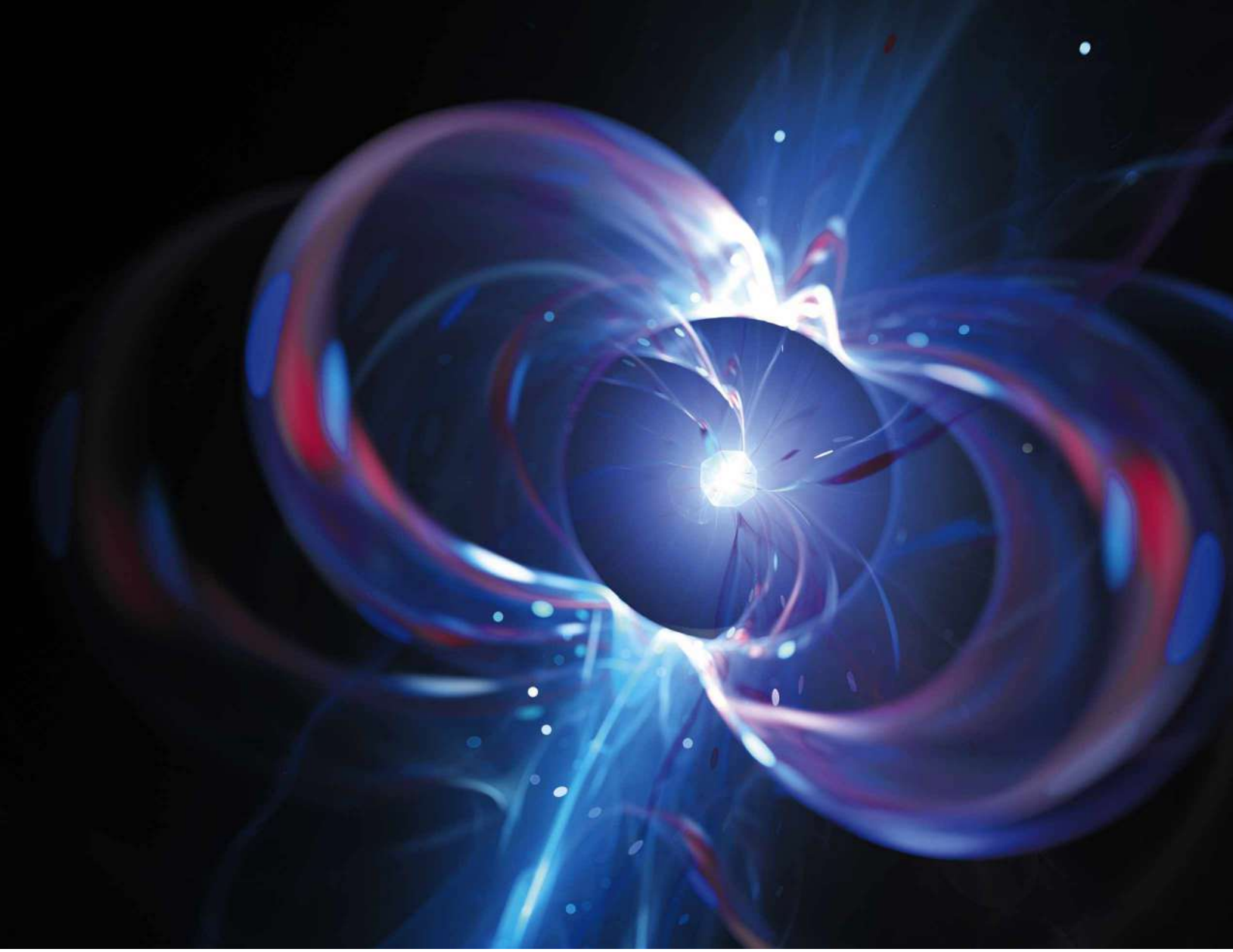
TYPE IA
Occurs when a white dwarf is swamped by matter from a companion star. A superluminous supernova is about 10 times as bright as a Type IA.



TYPES IB and IC
IB and IC supernovae happen in the implosion of the core of a star which has already lost its outer mantle of hydrogen and helium.



TYPE II
Type II supernovae are formed when a star of 8 to 50 solar masses implodes. A superluminous supernova is about 100 times as powerful as a Type II.



ABOVE Some supernovae mark the birth of a neutron star, which forms from the collapsed core of a supergiant star

able to hang on to any heavy elements forged in earlier generations of stars and blasted into space by ordinary supernova.

Another way for a star to be stripped of its mantle of hydrogen and helium is if it's in a close binary star system and the gravity of a massive companion star has stripped it off. "This seems the most likely possibility," says Nicholl.

A QUESTION OF POWER

The $64,000 question is of course: what powers these mega stellar explosions? An obvious possibility is that they're merely souped-up versions of standard supernovae, whose power source is ultimately gravitational energy.

To understand gravitational energy, think of slate falling off a roof onto the ground. The slate's gravitational potential energy (the energy it has due its height in Earth's gravitational field) is converted into the energies of motion, sound and heat. Similarly, when the core of a star implodes, it's like countless quadrillion slates falling, and results in a tremendous amount of gravitational energy that's converted into a tremendous amount of heat. It is implosion, ironically, that drives explosion!

In a superluminous supernova, the spectrum reveals that between 5 and 20 solar masses of oxygen are ejected. In comparison, two to four solar masses of oxygen are ejected in a Type Ic supernova, which occurs in a standard star stripped of hydrogen and helium. The implication is that the stars are only a few times bigger than the stars responsible for normal supernovae, and so a standard explosion is unlikely to make them 10 times as luminous. The clincher for why superluminous supernovae are *not* simply souped-up versions of standard supernovae is that a normal supernova stays bright for a month or so because it's powered by the radioactive decay of nickel-56 and cobalt-56, forged in the fury of the initial explosion. "However, something like 20 solar masses of such elements are needed to power a superluminous supernovae," says Nicholl. "Though we see about 20 solar masses of oxygen, we don't see an equivalent amount of nickel and cobalt."

Another possible mechanism for a superluminous supernova involves the blast wave, expanding through space at about 10,000 kilometres a second, slamming into a slow-moving circumstellar

shell of matter ejected by the star some time before the explosion. The rapid slowdown of the blast wave would shock heat the ejecta very efficiently, converting its energy of motion into prodigious amounts of heat and light. "The problem is we don't see any evidence of slow-moving stuff in the spectra of superluminous supernovae," says Nicholl.

This leaves a final candidate for the engine of superluminous supernova. When the core shrinks, the endpoint is a highly compact object, such as a neutron star. Such an object, with a mass comparable to the Sun, but merely the size of Mount Everest, would be expected to be spinning fast, for the same reason that an ice skater who pulls in their arms spins faster: conservation of angular momentum. In fact, such an object could be spinning as fast as 1,000 times a second! "Such an extraordinary flywheel has more than enough rotational energy to energise a superluminous supernova, if there is some way to transfer that energy outwards," says Nicholl. "Fortunately, there is."

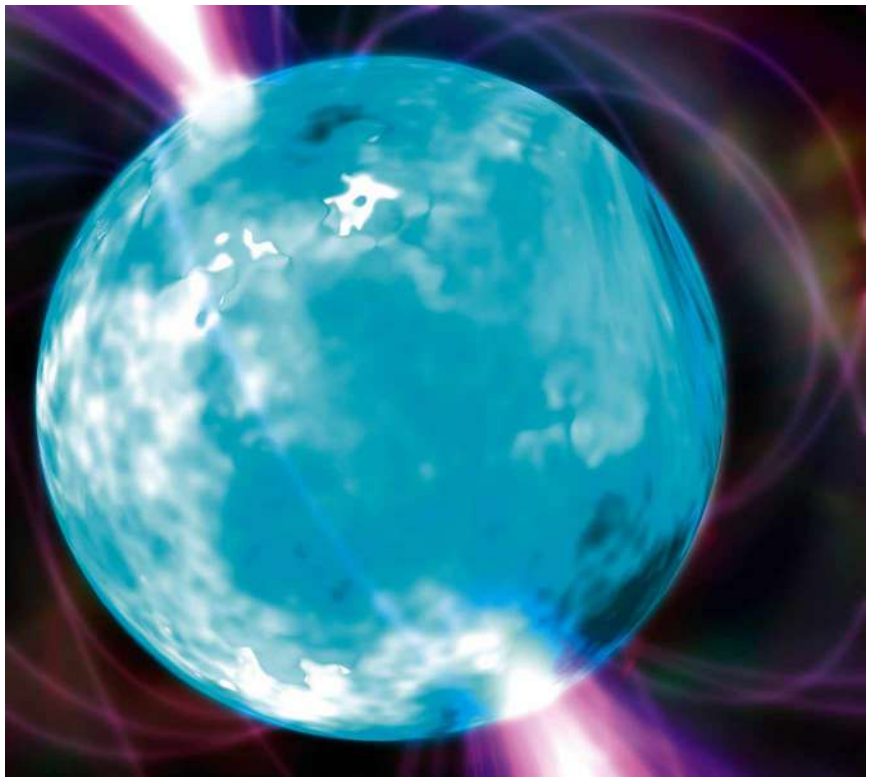
When the core of a star implodes catastrophically, any magnetic field that the star possessed is enormously concentrated and amplified. The neutron star may end up with a prodigious magnetic field – these neutron stars are known as 'magnetars'. The magnetic field of such a magnetar could be in the range 10^{12} (a trillion) to 10^{15} (1,000 trillion) gauss (a unit that measures magnetic fields). For comparison, even the minimal field is 100 billion times stronger than a fridge magnet.

The problem is that the bigger the magnetic field, the more it interacts with surrounding material and the faster this interaction 'brakes' the magnetar's rotation. "To keep a supernova bright for the month or so observed, a lower magnetic field is necessary," says Nicholl. "There is a sweet spot at about 10^{13} to 10^{14} gauss."

"I THINK THE MAGNETAR MODEL IS THE ODDS-ON FAVOURITE FOR POWERING MOST SUPERLUMINOUS SUPERNOVAE"

The precise mechanism by which the magnetar supplies energy to the material ejected by the star is not yet known. But Nicholl says there's a way to prove or disprove the idea of a magnetar-as-central-engine. Its magnetic field is so strong it will conjure electron-positron pairs out of the surrounding vacuum, and their subsequent annihilation should create a distinctive spike of high-energy light, or gamma rays. "The falloff of gamma rays should precisely track the spin down of the magnetar," says Nicholl.

"I think the magnetar model is the odds-on favourite for powering most superluminous supernovae," says Quimby. "Some supernovae



RIGHT A magnetar is a type of neutron star with an enormous magnetic field. Magnetars are a favourite candidate for powering superluminous supernovae

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mark the births of neutron stars, and tapping just a small fraction of the energy from such beasts ought to be enough to produce some remarkable fireworks."

GOING BACK IN TIME

But not everyone agrees that magnetars are the engines of superluminous supernovae. "I favour a mechanism where the ejecta from energetic supernova collide with massive circumstellar matter and the supernova kinetic energy is efficiently converted into radiation," says Dr Takashi Moriya of the National Astronomical Observatory of Japan. But he concedes: "There may not be a single mechanism that makes supernovae extremely bright."

Although it has taken almost two decades to find the first 100 superluminous supernovae, the discovery rate will soon be boosted by the Vera C Rubin Observatory when it begins operating in Chile in October 2023. The telescope will observe the whole sky, night after night. "This ability will utterly transform the field," says Nicholl. "Instead of 100 in 15 years, we're expecting to discover 1,000 superluminous supernovae every year!"

An even more mouthwatering prospect will be provided by NASA's James Webb Space Telescope, the successor to Hubble, which was due to launch in December 2021. With its 6.5m mirror (4.5 times the collecting area of Hubble), it will be able to detect superluminous supernovae at greater distances, which because of the finite speed of light, means at earlier cosmic times. At the dawn of the Universe, there were many more dwarf galaxies in existence than now because they had not had time to merge to form the giant galaxies, such as the Milky Way, that we see today. They were also depleted in heavy elements because stars had not had time since the Big Bang to synthesise them. And there are theoretical reasons to believe that the first generation of stars to form after the Big Bang were monsters – possibly more than 100 solar masses. "Superluminous supernovae could easily have been more common at the beginning of time," says Nicholl.

This raises an interesting possibility. The iron in your blood, the calcium in your bones, the oxygen that fills your lungs each time you take a breath... all of these were forged inside stars that lived and died, blowing themselves to smithereens, before Earth and the Sun were born. Perhaps superluminous supernova contributed

ABOVE The Vera C Rubin Observatory in Chile becomes operational in 2023 and will aid in the hunt for more superluminous supernovae

"INSTEAD OF 100 IN 15 YEARS, WE EXPECT TO DISCOVER 1,000 SUPERLUMINOUS SUPERNOVAE EVERY YEAR!"

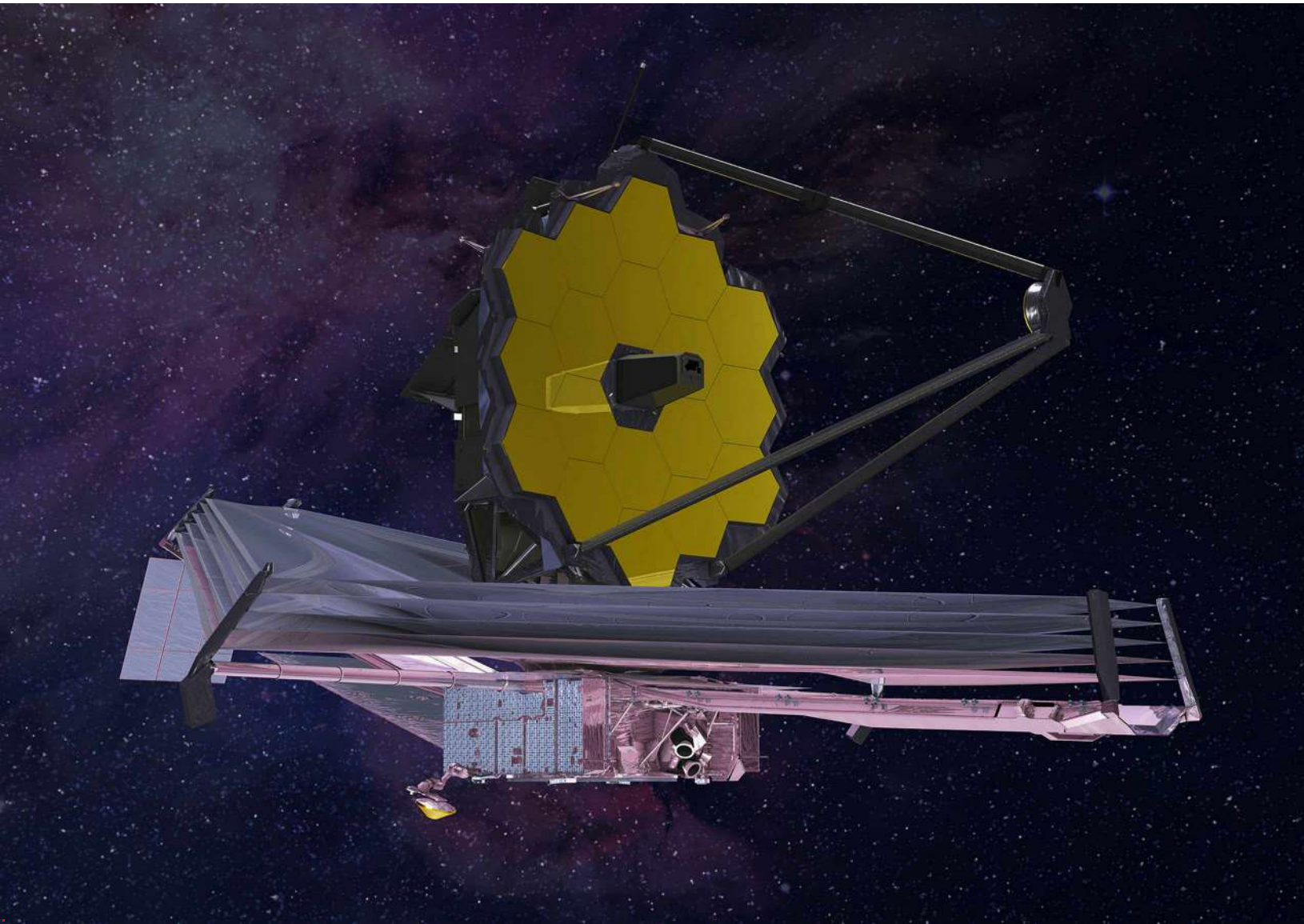
a significant fraction of the heavy elements in the Universe. In which case, you may not need to look far to see the fruits of the superluminous supernovae. Just hold up your hand!

The first exploding stars were recorded by Chinese astronomers about 2,000 years ago. But it was not until 1931 that astronomers realised there was a class of super-explosions and not until 2005 a class of super-super explosions. The obvious question is: are there even bigger stellar explosions out there that we have so far missed? "I wouldn't bet against it," says Nicholl.

"Superluminous supernovae may mark the limit of what is possible for supernovae – at least locally," says Quimby. "The big exceptions are the hypothetical pair-instability supernovae thought to exist only in the early Universe."

In a pair-instability supernova, expected to occur in a star of between 130 and 250 solar masses, the interior gets so hot that gamma rays inside conjure into existence electron-positron pairs. These reduce the thermal pressure opposing gravity trying to crush the core, triggering a catastrophic collapse and a titanic explosion that blows the star to smithereens. A pair-instability supernova would shine 100 times brighter than even a superluminous supernova. Such supernovae might be detected by the James Webb Space Telescope. "As a hunter of exotic explosions," says Quimby, "I like to think there are more surprises left to find in the Universe." **SF**

by **MARCUS CHOWN** *(@marcuschown)*
Marcus Chown is the author of Breakthrough: Spectacular Stories Of Scientific Discovery From The Higgs Particle To Black Holes *(£9.99, Faber & Faber).*



BELOW The James Webb Space Telescope will be able to peer further back in time, to a period when superluminous supernovae may have been more common

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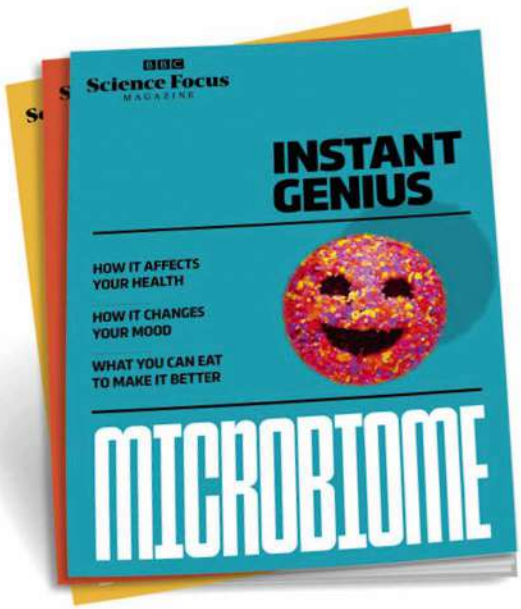

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... CAN WE RECYCLE CONCRETE?
... DO NOOTROPICS REALLY WORK?
... DOES DYSLEXIA EXIST IN WRITING SYSTEMS LIKE CHINESE AND JAPANESE?
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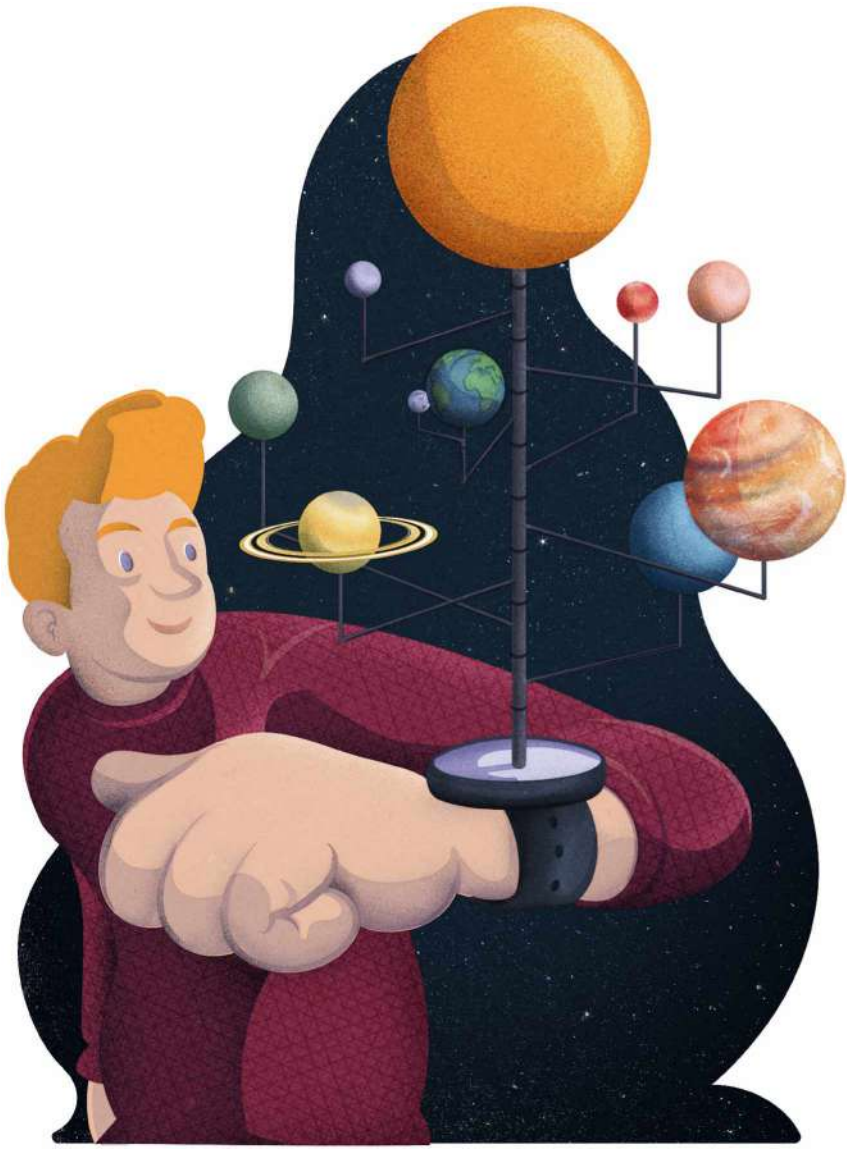

ILLUSTRATION: DANIEL BRIGHT

SHAUN DOYLE, BELFAST

HAVE WE DISCOVERED ANYTHING IN SPACE THAT WE NOW USE IN EVERYDAY LIFE?

A pure science like astronomy rarely contributes directly to our everyday lives – although, of course, it adds to our scientific, philosophical and cultural experience of the cosmos. The processes and phenomena discovered in space are generally of such a scale (in size, time or energy, for example) that they have liffle relation to the human experience. However, a notable exception is the research on nuclear processes occurring in stars which indirectly led to the development of nuclear power (and weapons). Beyond that we could list technologies prevalent in everyday life that were originally developed for astronomy (like digital cameras and MRI scanners) or discoveries actually made in space (on the ISS, for example) which have led to important innovations (including pharmaceuticals, or treatments for Alzheimer's and Parkinson's). Of course, every time you check the time you are using the astronomical discoveries of humankind. ***AG***

NATURE'S WEIRDEST CREATURES...

WARTY COMB JELLY

Starter for 10: What's 97 per cent water, eats its own offspring and has a 'transient anus'? Meet the warty comb jelly, a cannibalistic creature with the world's weirdest party trick. Most of the time, this jellyfish-like animal has no anus. Then, hey presto, just when it needs one, one magically appears, only to disappear moments later when defecation is done. It's the only animal known to science to have such a bit of anatomy.

The anomalous animal, which is native to the east coast of America, belongs to a group of creatures called ctenophores. Members have translucent, blobby bodies and rows of iridescent cilia, which they use to propel themselves around the ocean and hoover up microscopic prey. But where other ctenophores have one, or sometimes even two permanent bottom holes, the warty comb jelly has an ephemeral orifice that comes and goes. When it needs to poo, part of its gut fuses with the outer epidermal layer, which then puckers up to form the fleeting orifice. Adults the size of golf balls go with reassuring regularity, around once an hour, and if it all sounds like a crock of excrement, think again. Scientists believe the arrangement may represent an intermediate stage in the evolution of the anus. *HP*

PAUL REED, LINCOLN

HOW DO WE KNOW THE SHAPE OF THE UNIVERSE?

When astronomers talk about the 'shape' of the Universe, they are talking about something more specific than whether it is a sphere or a cube, for example. Einstein's General Theory of Relativity allows three shapes, or geometries, for the Universe. These are 'flat', 'closed' or 'open'. It's difficult to envisage these shapes in terms of the Universe, but they can be compared to a sheet of paper (flat), a sphere (closed) or a saddle (open). The shape of the Universe determines whether it will expand forever (or eventually collapse), and whether it's finite or infinite. Which shape it is depends on its total density and its rate of expansion.

The most convenient way of determining the shape of the Universe is to use the cosmic microwave background (CMB), the relic afterglow of the Big Bang. Small spatial variations in the temperature of this faint light are produced by sound waves moving through the early Universe. The actual size of these hot or cold spots can be computed accurately and then compared to their measured size. This is like doing a vast trigonometry measurement across the entire Universe and revealing the geometry of space.

Over the past few decades, astronomers have measured the temperature fluctuations in the CMB very accurately. The results have shown to a high degree of accuracy that the density of the Universe is such that it expands in every direction without any positive or negative curvature, in other words, the Universe is 'flat'. This flat Universe is a major component of the standard cosmological model.

It should be pointed out that a flat Universe is not universally accepted. Some studies have shown that other measurements, such as the amount of gravitational lensing – how much the CMB is distorted by the gravity of matter in its path – is more consistent with a closed Universe. ***AG***

NICK HUNTER, NORFOLK

WHY DO KIDS THROW UP SO MUCH?

Suckling infants throw up because they swallow a lot of air along with the milk. So, rather than vomiting, they are really just doing very wet burps. But slightly older children do seem to be more prone to vomiting than adults, and it's likely this has evolved as a protective strategy. For adults, the calorie value of slightly gone-off food or weird berries may have outweighed the risk from the toxins. But children are more vulnerable to food poisoning and disease because of their lower body weight and less developed immune systems. Throwing up at the first sign of trouble represents a better-safe-than-sorry approach. ***LV***

CROWDSCIENCE

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NEIL CRIMMINGS, SWANSEA

CAN WE RECYCLE CONCRETE?

Concrete can be recycled by grinding it up, then using screens to separate fine and coarse materials, magnets to remove steel, and water oatation to remove other unwanted materials. It can then be used to form hardcore sub-bases underneath new structures, gravel for paths or driveways, or even act as the aggregate for new concrete. It's harder to recycle concrete if it contains lots of contaminants, but it's really worth trying: recycling means less gravel mining and less landfill, so recycling one tonne of concrete could save 6,182 litres of water and 900kg of CO_2.

Sometimes only about 30 per cent of the materials in new concrete is recycled, because its performance may otherwise be reduced. But new processes using chemical additives can help break down old concrete into sand, gravel and limestone, sequestering 60kg CO_2 per tonne and enabling much higher quality new concrete to be made from recycled materials.

Researchers at Tokyo University have also suggested a new kind of concrete that is inspired by the way some aquatic organisms harden into fossils over time. They extract calcium from discarded concrete and combine it with carbon dioxide from industrial exhaust or even from the air, making new 'calcium carbonate concrete'. ***PB***

ALAMY, SCIENCE PHOTO LIBRARY, GETTY IMAGES ILLUSTRATION: DANIEL BRIGHT

HOW DOES SOIL STORE CARBON?

Soil locks up carbon via the process below. But since the invention of agriculture 12,000 years ago, the conversion of natural ecosystems like grassland and forests has released 110 billion tonnes of carbon from the topsoil into the air. Now scientists are looking at different land management techniques that could reverse this process and use the soil as a long-term carbon sink.

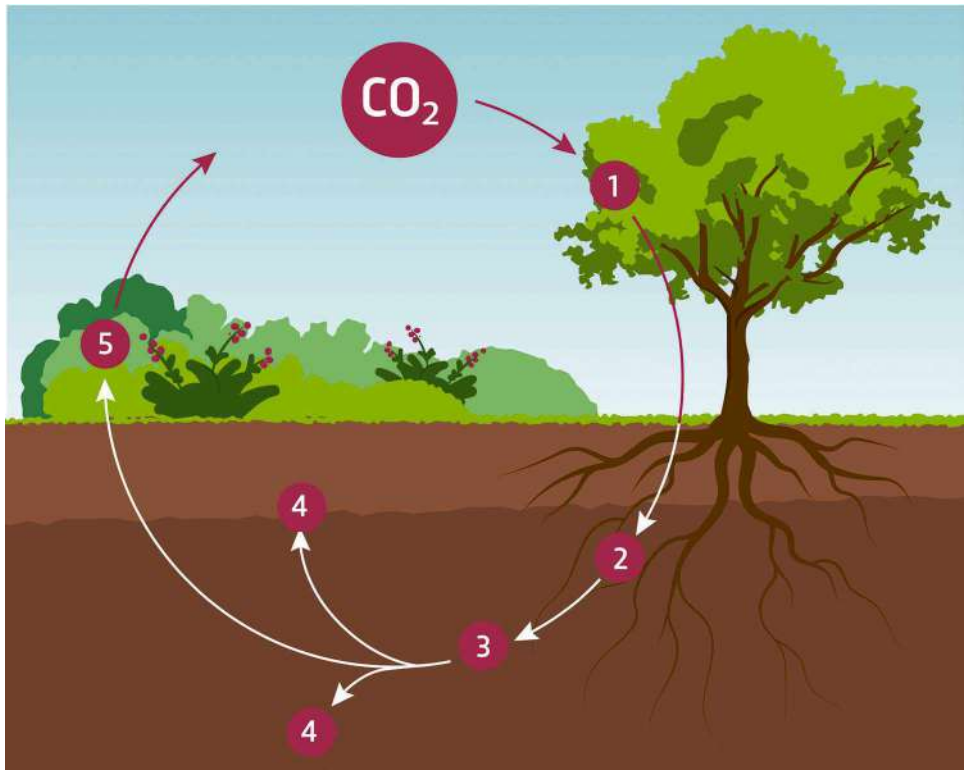
1 PRODUCTIVE SOIL
Only about 42 per cent of the carbon in a forest is contained in the plant matter above the ground. The rest is made up by the roots, soil organisms and partially decomposed matter in the soil.

2 SETTING DOWN ROOTS
Plant roots grow into deeper layers of soil. When the plant dies, the carbon in the roots is left there – often out of reach of most of the soil microorganisms that would break down the organic matter.

3 TRAPPED CARBON
Highly decomposed carbon forms particles small enough to chemically bind to the clay in soils, which can stay trapped below ground for hundreds or thousands of years.

4 GOING DEEPER
Some carbon compounds are water soluble, and rainwater steadily moves them downwards to even deeper rock strata. High organic content in the soil increases the water retention, which not only helps to drive this process but makes the land more resistant to droughts.

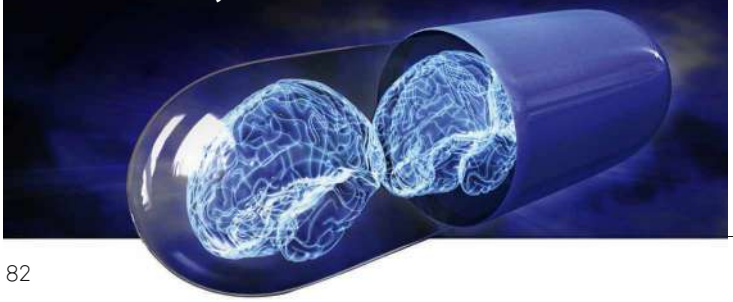
5 HEALTHY POPULATION
Soils with higher organic carbon content also support a richer population of microorganisms and contain more nutrients. This increases plant growth and creates a virtuous cycle that is good for both farmers and the environment. ***LV***



FRASER STEWART, CARLISLE

DO NOOTROPICS REALLY WORK?

A nootropic – sometimes referred to as a 'cognitive enhancer' – is any kind of drug or dietary supplement that supposedly boosts your mental performance in some way. Caffeine has real benefits for concentration. But more controversial is the use of prescription drugs as cognitive enhancers, such as methylphenidate (used in the treatment of ADHD) and Modafinil (used to treat narcolepsy). While research is ongoing, the current evidence suggests that the benefits of such drugs for attention and memory performance is modest and should be weighed against any potential risks, including anxiety, dependence and over-confidence. ***CJ***



ANDREA LEAKE, SOUTHAMPTON

DOES DYSLEXIA EXIST IN WRITING SYSTEMS LIKE JAPANESE AND CHINESE?

Chinese characters represent whole syllables, whereas Western languages use letters to represent phonemes (the individual sounds that make up each syllable). Japanese has several different character sets that combine elements of both systems. Dyslexia is less common among Chinese speakers, but it definitely exists. However, a 2004 study at the University of Hong Kong used MRI scans to show that different regions of the brain were involved with the dyslexia of Chinese speakers versus English speakers. This suggests that dyslexia is not a single disorder and there are examples of people who are dyslexic in one language but not in another. ***LV***

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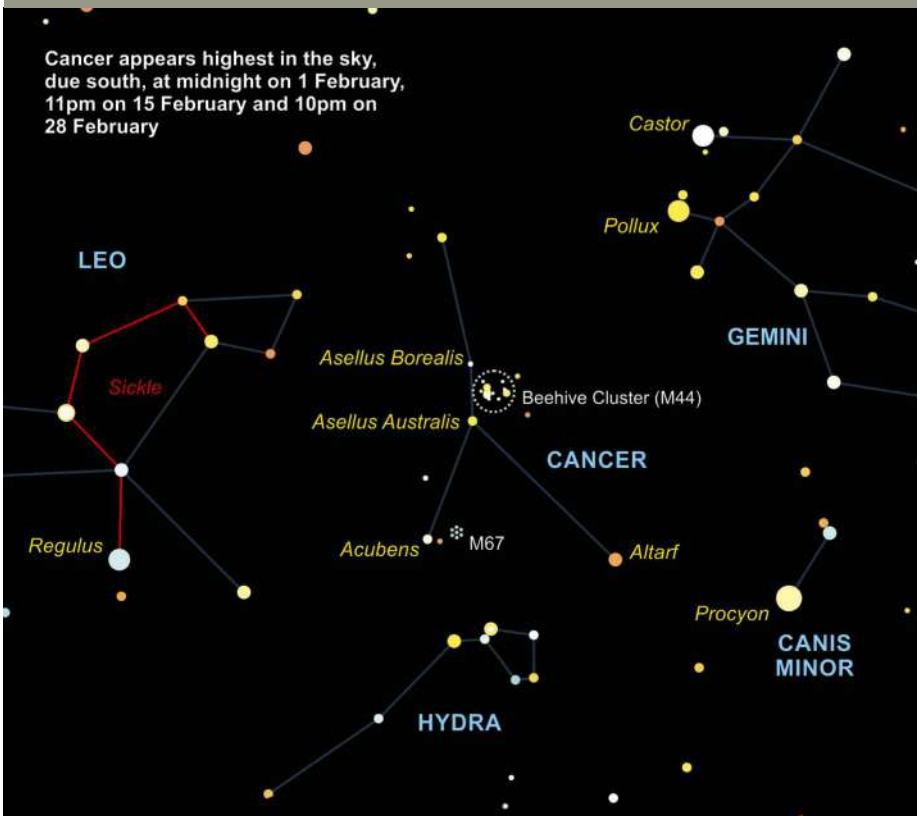
ADAM MARSH, LONDON

WHY DOES LEFT AND RIGHT MATTER ON HEADPHONES?

Sound moves quite slowly. An echo demonstrates how slowly it moves – shout at a distant building and you can hear your voice bounce back at you with a slight delay. It moves slowly enough (330m/s) that your brain can detect a time difference between the sound arriving at your left ear and your right ear. This is called the interaural time difference. Our ears can detect interaural time differences as small as 10 microseconds. So, if someone speaks on your left, your brain knows the sound is coming from the left because it takes a fraction of a second longer for the same sound to reach your right ear. Stereo music uses this to give the illusion that sound is coming from different directions, and headphones provide the best way to experience that illusion as they push the music directly to each ear. But to hear stereo properly, you need the headphones on the right way round, otherwise, all the sounds will be reversed – left will come from the right and vice versa, and sounds from the front will sound like they're coming from behind you. You won't notice any difference for mono audio, but backwards stereo sound makes watching movies a bit disconcerting. ***PB***

ASTRONOMY FOR BEGINNERS



CANCER THE CRAB

WHEN: LATE WINTER

The trick to locating faint constellations is to use the more recognisable ones as guides. This certainly helps with the faint constellation of Cancer the Crab. To find this heavenly crustacean you'll need to identify the stars on either side of it. Start from Orion, identifying the bright blue supergiant Rigel in the southwest corner. Extend a line from Rigel through red-supergiant Betelgeuse in the opposite corner. Keep the line going for twice the distance to bring you to Castor and Pollux. These are the two bright stars in Gemini, Castor is the one to the north.

Next, locate the pattern of the Plough (or Saucepan) which is balancing on the end of its handle midway up the sky, above the northeast horizon before midnight. Extend the pan's side nearest the handle, towards the right until you arrive at the bright star Regulus in Leo. Above Regulus is a backwards question mark star pattern known as the Sickle.

Under a clear, dark sky look for a mistiness slightly below the mid-point of an imaginary line connecting Castor to Regulus. This is the Beehive Cluster, M44, an open cluster located at the heart of Cancer. Binoculars show it well.

An alternative name for M44 is Praesepe, meaning 'manger'. It sits within a box formed from four dim stars, the brighter two to the east being known as Asellus Borealis and Asellus Australis: the Northern Donkey and Southern Donkey.

The rest of Cancer resembles an inverted-Y, none of its stars are particularly bright. The open end of the Y lies south of M44, marked by Acubens to the southeast and Altarf to the southwest. Using binoculars or a small telescope, the open cluster M67 can be seen slightly west of Acubens. This appears dimmer and smaller than M44 because it's much farther away; nearly 3,000 light-years for M67 compared to 610 light-years for M44. *PL*

DEAR DOCTOR...

HEALTH QUESTIONS DEALT WITH BY *SCIENCE FOCUS* EXPERTS

ALEX WARREN, LONDON

WHY AM I SUCH A CREATURE OF HABIT?

A friend of mine kept a dozen or more boxes of the same breakfast cereal lined up in his kitchen. He enjoyed this particular cereal and did not want to waste any brainpower seeking an alternative. What he lost in variety and spontaneity, he made up for in efficiency. That, in a nutshell, is the virtue of habits – they're automatic, learned behaviours that provide a quick answer to life's puzzles.

Without habits, you'd be paralysed by endless deliberation from the moment you woke each day – whether to shower then eat, or eat then shower, what to eat, what to wear, which route to take to work, or where to park.

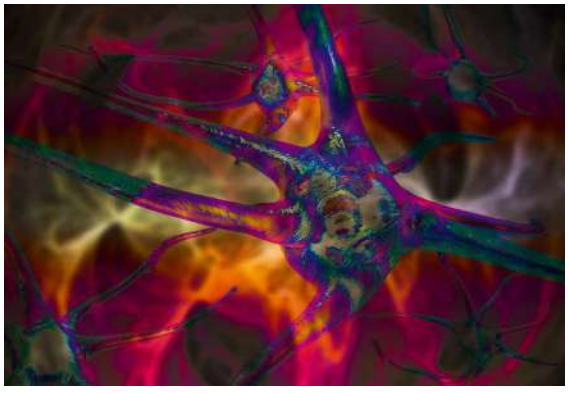
Habits can also be comforting. If you follow the same routines each day, then you mostly know what to expect. If this suits you, then in personality terms, you are probably a low scorer in 'openness to experience', a tendency that tends to grow with age. A downside to habits is that not only are some of them obviously unhealthy, but having too many can hamper your creativity and deprive you of serendipity.

If you want to change, bear in mind that habits tend to be triggered by cues in the environment – that cereal box in the kitchen, the café on the way to work. That's why holidays are such a great antidote. Put yourself in novel situations and you're forced to think afresh rather than rely on old habits. ***CJ***

HANNAH WILKINSON, SOMERSET

DOES DRINKING MILK CREATE PHLEGM?

No, it's a myth that started a long time ago. The texture of milk can make some people feel their saliva is thicker, but there's no evidence that it creates phlegm. The myth may have hung around because milk is an emulsion, meaning it has droplets of one liquid suspended in another liquid. When a person drinks milk, it mixes with their saliva and this can make it feel more viscous. This can make people feel like there's more mucus, but it's just aggregates of milk emulsion lingering in their throat. Milk is an important source of nutrition, and should not be avoided because of this myth. ***NM***



NAOMI JONES, PONTYPRIDD

HOW DOES CONCUSSION AFFECT VISION?

A concussion is a type of brain injury that happens when a blow to the head makes the head move back and forth with a lot of force. More than half of the brain's pathways are dedicated to vision and eye movement, so a diffuse brain injury such as a concussion will often affect the visual system. Most of the time this happens from damage to the optic nerve, either directly or indirectly. Even a mild concussion can cause problems with vision, such as blurring, sensitivity to light and difficulty focusing on objects. Severe concussions can cause blindness and double vision. ***NM***

CHRIS LANGHAM, HARROW

IS SUNCREAM BAD FOR CORAL REEFS?

Over the last decade, scientific studies have shed light on the toxic effects that many widely used sunscreen ingredients can have on coral reefs. To date, this research has focused mostly on how chemical UV filters, such as oxybenzone, can lead to coral bleaching and disrupt coral reproduction. As a result, some countries have banned these ingredients. But scientists caution that there is still a lot we don't know. Many products using mineral rather than chemical filters are now marketed as 'reef-friendly', but these alternative ingredients haven't undergone proper scrutiny, and the wider impacts of sunscreen components on marine and freshwater environments are still largely unknown. ***AFC***

QUESTION OF THE MONTH

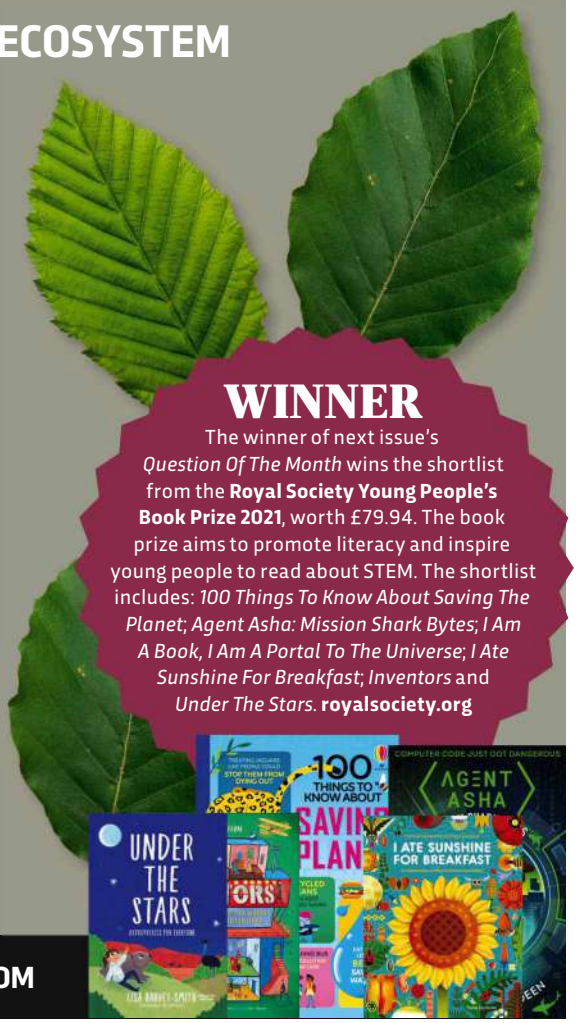
BELLE FORD, SOUTHPORT

WHY DO DIFFERENT PLANTS IN THE SAME ECOSYSTEM EVOLVE DIFFERENT-SHAPED LEAVES?

From the big, flat paddles of the South American monstera to the tiny, round bobbles of the African string-of-beads plant, leaves come in a bewildering variety of shapes and sizes. Their main job is to harvest sunlight and then use this energy to help the plant make food via photosynthesis. Carbon dioxide and water are converted to glucose and oxygen inside specialised structures called chloroplasts.

Leaf structure has a big impact on this process. Leaves with bigger surface areas, for example, can pack in more chloroplasts and absorb more sunlight, which means they can make more glucose. It sounds like a good thing, only those same large leaves may be more prone to heat loss, which is a problem if the plant lives somewhere chilly. There's a trade-off to be had; nutrients versus heat loss, and over time, leaf shape evolves towards the optimal solution. The problem, however, is that plants are bombarded with a constant maelstrom of trade-offs, including the ability to transport water efficiently, minimise water loss, repel pathogens and deter hungry herbivores. Different species of plants living in the same ecosystem sometimes evolve different leaf shapes because often, there's more than one solution to the trade-offs that they face.

Hornbeams and beech trees, for example, live in the same deciduous woodlands and have evolved similarly shaped leaves, fringed with tiny serrations. Meanwhile, oak trees, which live in the same ecosystem, have evolved lobed leaves with smooth edges. Subject to almost identical environmental conditions, and the same array of trade-offs, the hornbeam and the beech have arrived at one answer to the problem of leaf design, while the oak tree has adopted a different, but equally excellent solution. ***HP***



WINNER

The winner of next issue's *Question Of The Month* wins the shortlist from the **Royal Society Young People's Book Prize 2021**, worth £79.94. The book prize aims to promote literacy and inspire young people to read about STEM. The shortlist includes: *100 Things To Know About Saving The Planet; Agent Asha: Mission Shark Bytes; I Am A Book, I Am A Portal To The Universe; I Ate Sunshine For Breakfast; Inventors* and *Under The Stars*. **royalsociety.org**

EMAIL YOUR QUESTIONS TO **QUESTIONS@SCIENCEFOCUS.COM**

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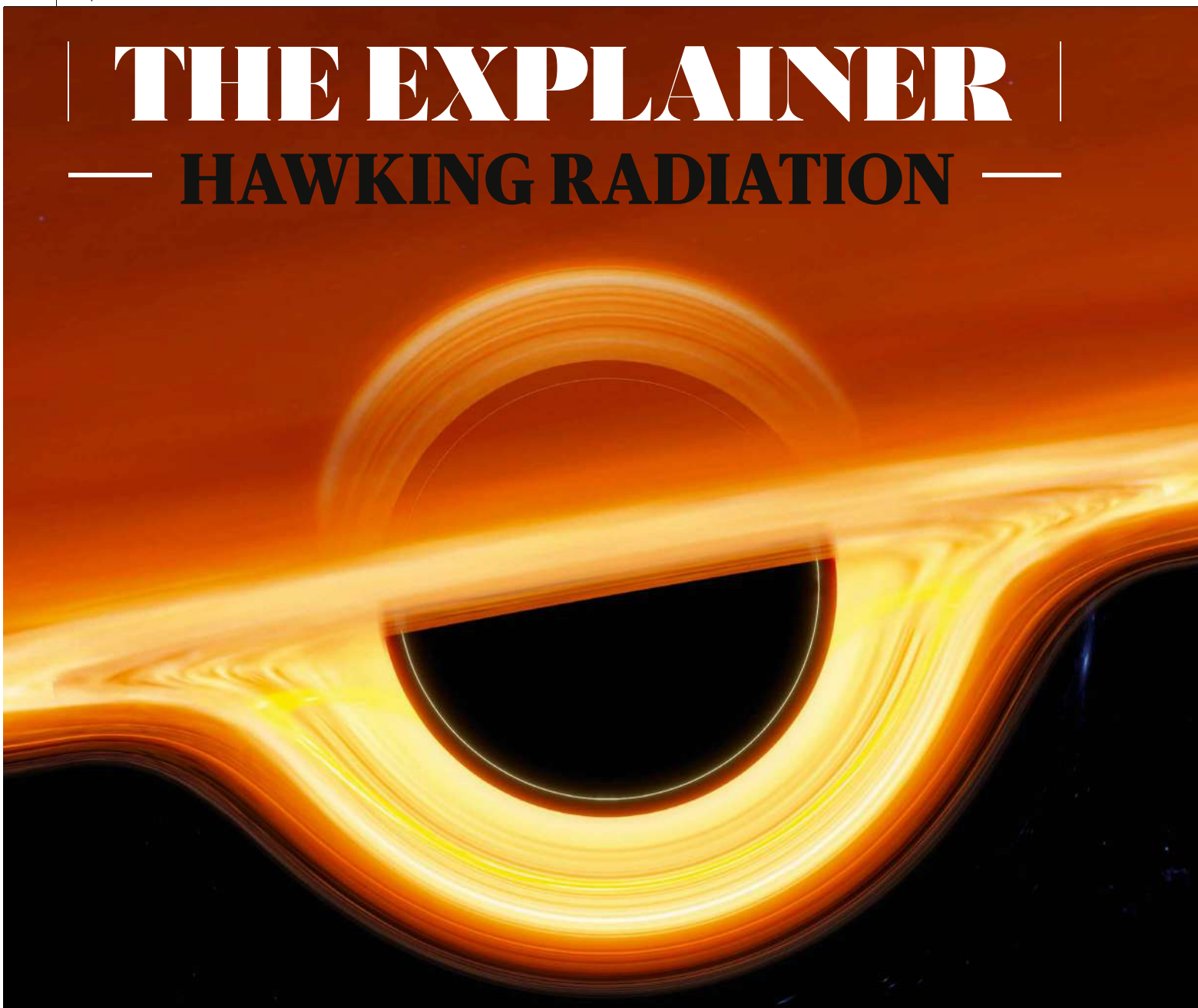
THE EXPLAINER

HAWKING RADIATION



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WHAT IS HAWKING RADIATION?

In the 1970s, physicist Stephen Hawking tried to answer an apparently simple question: do black holes have a temperature? His analysis led to the concept which now bears his name: Hawking radiation. Not only did Hawking show that black holes radiate energy, he showed that they shrink incredibly slowly and eventually explode in a flash of gamma rays.

The idea of Hawking radiation is based on the fact that empty space isn't actually empty. This is perhaps a difficult concept to grasp. Although empty space contains no mass, no particles or quanta of energy, the quantum fields which define them still exist in the vacuum of space. The usual explanation is that these fields, because they are not required to have zero energy, can create pairs of 'virtual particles', normally a particle-antiparticle pair which quickly annihilate each other. But near a black hole, the explanation goes, it is possible for one of those particles to disappear inside the black hole and be lost forever, while the other one escapes as Hawking radiation.

This explanation, although commonly used, is not entirely complete. Hawking radiation is actually the result of how gravity affects space-time, as described by General Relativity. The quantum fields in empty space obey Heisenberg's uncertainty principle, which means there is a limit to the certainty with which we can know their energy, or the time at which a specific energy can be assigned to them. Since a gravitational field bends space-time and affects the local passage of time, this means that regions of space-time with different gravitational curvatures cannot agree on the energy of the quantum fields. It is this difference in the energy of the vacuum at different locations in the gravitational field of a black hole which creates so-called 'virtual particles'.

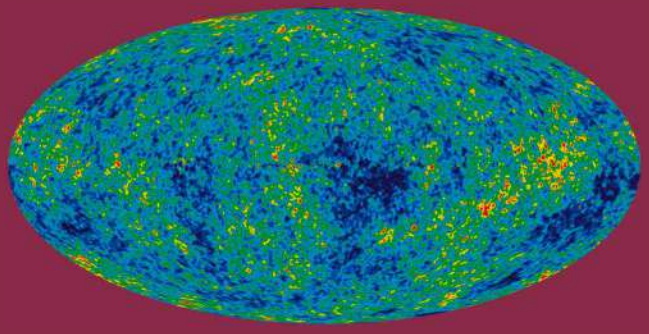
DO BLACK HOLES LIVE FOREVER?

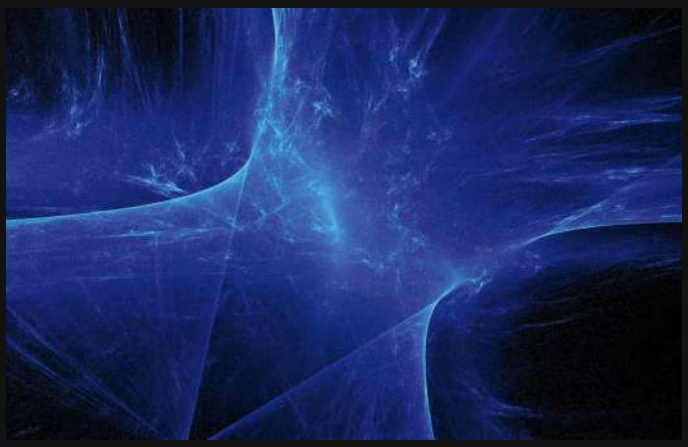
One of the conclusions of Hawking's work was that black holes don't live forever. They eventually evaporate, in a very slow and mundane fashion. The release of Hawking radiation gradually reduces the mass of the black hole. So black holes that aren't actively sucking in new material will slowly shrink and ultimately vanish. The timescales for this evaporation are immense. For example, a black hole of one solar mass would take 10^{64} years to completely evaporate, whereas the age of the Universe is only of order 10^{10} years.

CAN WE DETECT HAWKING RADIATION?

Hawking managed to answer his original question of whether a black hole has a temperature. They do, but those temperatures are extremely small. What's more, Hawking showed that the amount of energy released by a black hole is inversely proportional to its mass. So, oddly, the higher the black hole's mass, the smaller its energy release and temperature. A black hole of one solar mass (one solar mass is equal to the mass of our Sun) might have a temperature of about 10^{-8}K while a million solar-mass black hole would be about 10^{-14}K. These temperatures, only marginally above 'absolute zero', are minuscule in comparison to the temperature of the Cosmic Microwave Background (CMB) – the relic radiation of the Big Bang which pervades all of space. It also appears that the Universe cannot routinely produce black holes smaller than about 2.5 solar masses, so finding really small and hence hot black holes isn't an option. It's therefore likely that detecting Hawking radiation is virtually impossible.

There is one possibility though. Some astronomers hypothesise the existence of 'primordial black holes'. These may have formed due to density fluctuations in the early Universe and may account for some of the mysterious dark matter that still eludes astronomers. Crucially, primordial black holes are not constrained by their size, so there is a chance that low-mass black holes may exist. These may emit sufficient Hawking radiation to be detected and, since their lifetimes are short compared to larger black holes, could reveal themselves in a flash of gamma rays during their dying moments.





WHAT IS THE BLACK HOLE INFORMATION PARADOX?

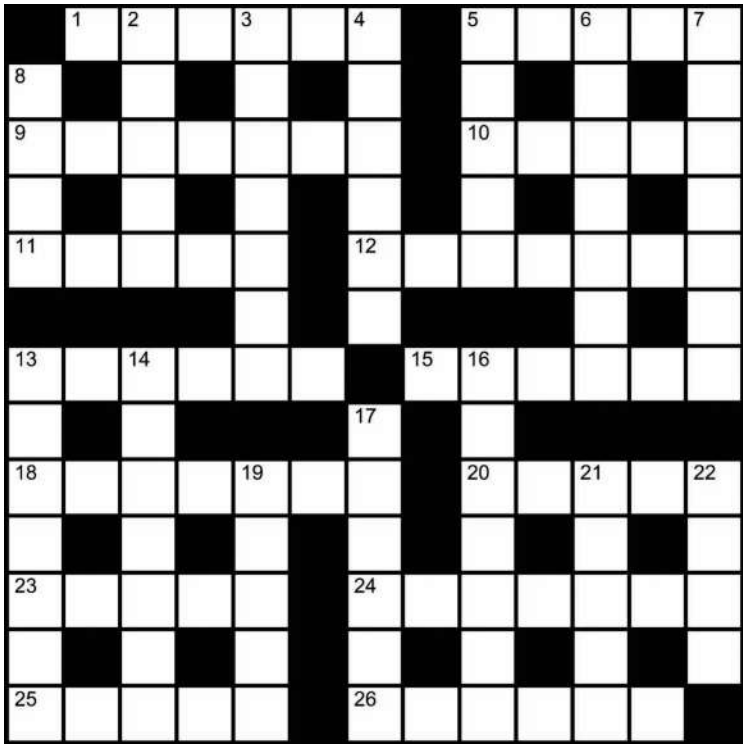
The evaporation of mass from a black hole due to Hawking radiation leads to a troubling problem known as the 'information paradox'. One of the core principles of quantum mechanics states that 'information' cannot be destroyed. This means that, for example, if we have complete information of a system of particles, we can predict the future and the past states of that system.

The information held by particles that cross the event horizon of a black hole is forever 'lost' to us because it can never return. That isn't a problem if the information remains intact within the black hole. The problem is that the black hole loses mass through Hawking radiation, but does not return that information to the accessible part of the Universe. Eventually the black hole disappears altogether and with it the information it has swallowed, violating the rules of quantum mechanics. The search for a resolution to this paradox has led to interesting new physics, but ultimately it may require a complete theory of 'quantum gravity' which, frustratingly, remains one of the unsolved problems of physics.

by ALASTAIR GUNN
Alastair is an astrophysicist and science writer at the Jodrell Bank Observatory, University of Manchester, as well as asociate editor of the Royal Astronomical Society's Astronomy & Geophysics *magazine.*

CROSSWORD

PENCILS AT THE READY!



ACROSS

1 Journalist spreading bile is not too bad (6)
5 Opening of composition, noisy and obscure (5)
9 Replaces oil that's just below the surface (7)
10 Odds are level on Sunday (5)
11 Wander aimlessly in a lot of snow (5)
12 Sailor acquires anger, being cross (7)
13 Useful, pursuing second drink (6)
15 Extravagant celebration is rubbish and alien (6)
18 Sprint back with energy to number in cell (7)
20 Put off being freed indefinitely (5)
23 Ring about daughter getting a bicycle part (5)
24 Work at home repeatedly, having zero judgment (7)
25 Tried working when exhausted (5)
26 Entertain fellow with some beer (6)

DOWN

2 City of the French bishop – excellent (5)
3 Transported around lake that's swollen (7)
4 Listen out and sign up (6)
5 Caught spool in a basket (5)
6 Former pupil likes strange monolith (7)
7 Decline of French perfume (7)
8 Employed American keys (4)
13 Place to play is small – also mine (7)
14 In pieces, like below (7)
16 Reversing downfall (7)
17 Routed differently, another way round (6)
19 Looked for small light – go back earlier (5)
21 Loud stream is an unnecessary extra (5)
22 Manage equation's first symbol (4)

ANSWERS

For the answers, visit **bit.ly/BBCFocusCW**
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POPCORN SCIENCE

Could the Moon fall out of the sky?

We dig into the science of *Moonfall*, Roland Emmerich's latest apocalypse-fest

by STEPHEN KELLY

When the Moon hits your eye like a big pizza pie that's a... *Moonfall*, the new disaster movie from Roland Emmerich in which the Moon – for reasons that are not yet clear – falls out of the sky and crashes to Earth. Such a premise raises inevitable questions. How has the Moon fallen out of its orbit? What does that mean for the Earth? How can it be stopped? And most importantly of all, should we be staring up at our own real-life Moon, shaking our fists and shouting at it to stay where it belongs?

Dr Tony Cook, a physics lecturer at Aberystwyth University, doesn't think so. He is confident that, if left alone, the Moon is not in any danger of suddenly dropping from space. "There's an equilibrium between the Earth and the Moon," he says. "It's a balancing point called the barycentre and the two bodies rotate around that." This point, he explains, is positioned closer to the Earth than the Moon, inside the Earth's surface. "It's a bit like a see-saw," he says. "If you've got a really heavy person on one end and a lightweight on the other, the balancing point has to be more towards the bigger person."

But what if the Moon wasn't left alone? The trailers for *Moonfall*, after all, suggest malicious intent from shadowy extraterrestrials. What could possibly knock the Moon off its course? "If you're an alien, I think you would need to put some propulsion engines on the lunar surface," Cook says. "I think you could probably deflect the orbit of the Moon over a long period of time, but you would need an enormous amount of energy to do that, and probably have to do it gently otherwise the Moon might fall to pieces. A similar method has been proposed to change the direction of asteroids."

If evil aliens did manage to push the Moon towards Earth over the course of many, many years, the effects on our planet would be devastating. "If the Moon was even half the distance away, the tides would be eight times stronger than they are at present," says Cook. "So if the Moon got really close to the Earth, you'd have massive tides to contend with. There would be a lot of coastal flooding. There would be a lot more gravitational influence on the interior of the Earth, so you might also churn up and heat some mantle, leading to a lot more volcanism and earthquakes."

Okay, and what about *Moonfall*'s portrayal of the Earth's oceans being sucked into the sky? "I don't think that would happen," says Cook, laughing like a man who has just been asked a very stupid question. "They'd certainly be swirling around quite a lot more. You might get some tsunamis. But water going up into the air? I imagine not."

Moonfall, of course, does have something of a real-life parallel. At the time of writing, NASA has warned that a 'wobble' in the Moon's orbit during the mid-2030s could contribute to severe flooding. This wobble, explains Cook, is part of a natural 18.6-year cycle in the Moon's orbit – half of which, thanks to fluctuations in the Moon's gravitational pull, is spent suppressing tides, the other half amplifying them. "It is something that has been with us over recorded history," he says, "but in the future, combined with rising sea levels, it might just be the straw that breaks the camel's back in some low-lying parts of the world."

Proof, yet again, that the dangers of reality are often far more worrying and far less exciting than they are on the big screen. *Moonwobble* just doesn't have the same ring to it. SF

VERDICT
Astronomers rejoice, the Moon will be staying put for the foreseeable future. Huzzah!

by STEPHEN KELLY *(@StephenPKelly)*
Stephen is a culture and science writer, specialising in television and film.

ILLUSTRATIONS: ADAM GALE, MANUEL STEVENS, CHRISTINA HALL

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